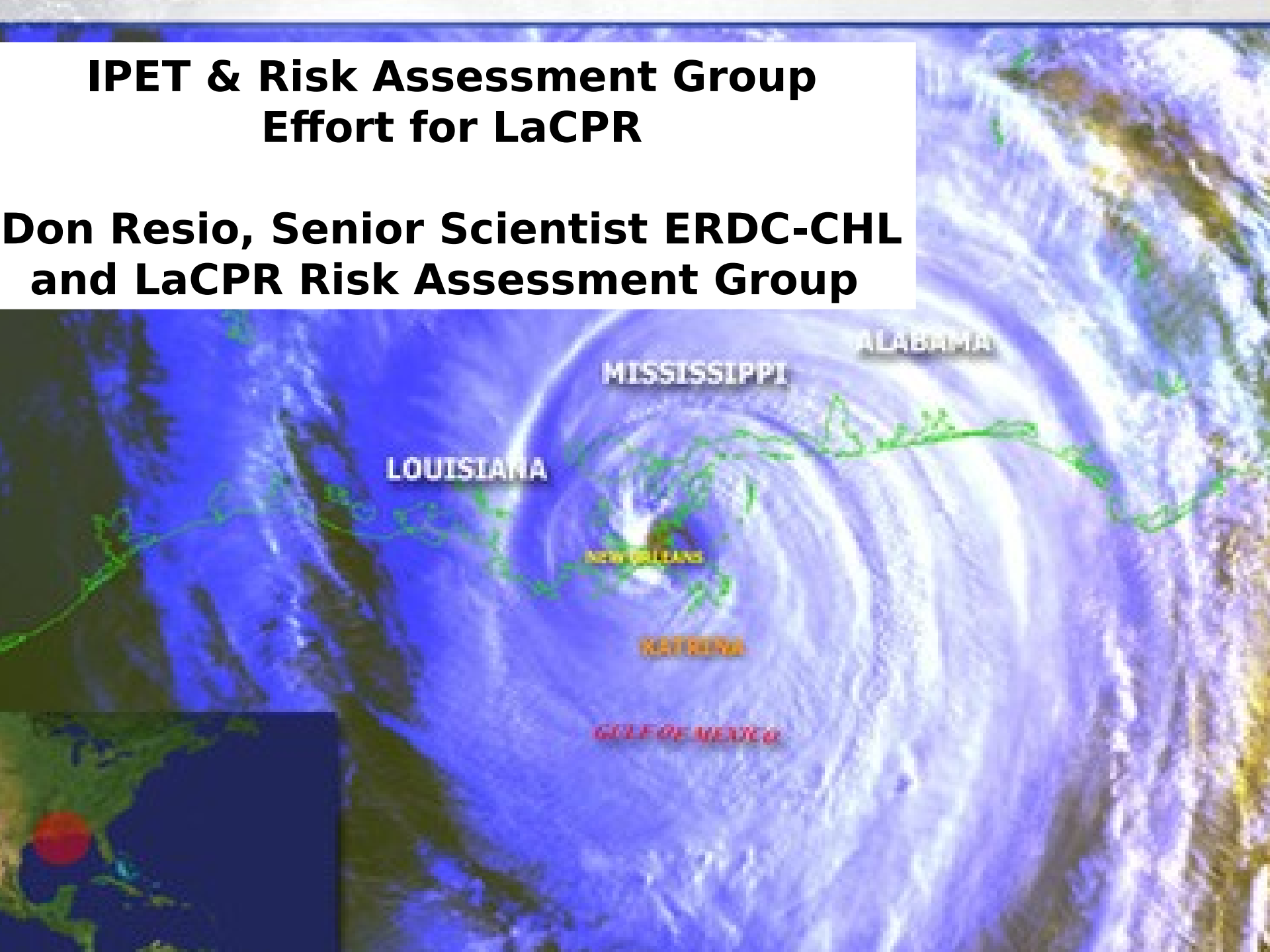
IPET & Risk Assessment Group Effort for LaCPR

Don Resio, Senior Scientist ERDC-CHL and LaCPR Risk Assessment Group



OUTLINE:

- **Brief discussion of IPET findings & risk methodo**
- **Development of Surge Potential and Storm Ranl**
- **Characteristics of strong hurricanes in Gulf of M**
  - **- tracks**
  - **- decay during approach to land**
  - **- interrelationships among parameters**
- **Statistical estimates for risk**
  - **- multivariate probability space**
  - **- single site versus area probabilities**
  - **- return periods of Cp at landfall**
- **Climatic variability??**
- **Where we are & Future directions**

Some Key IPET findings:

1. Wind fields are of primary importance to accuracy of surge estimates (PBL model + data).

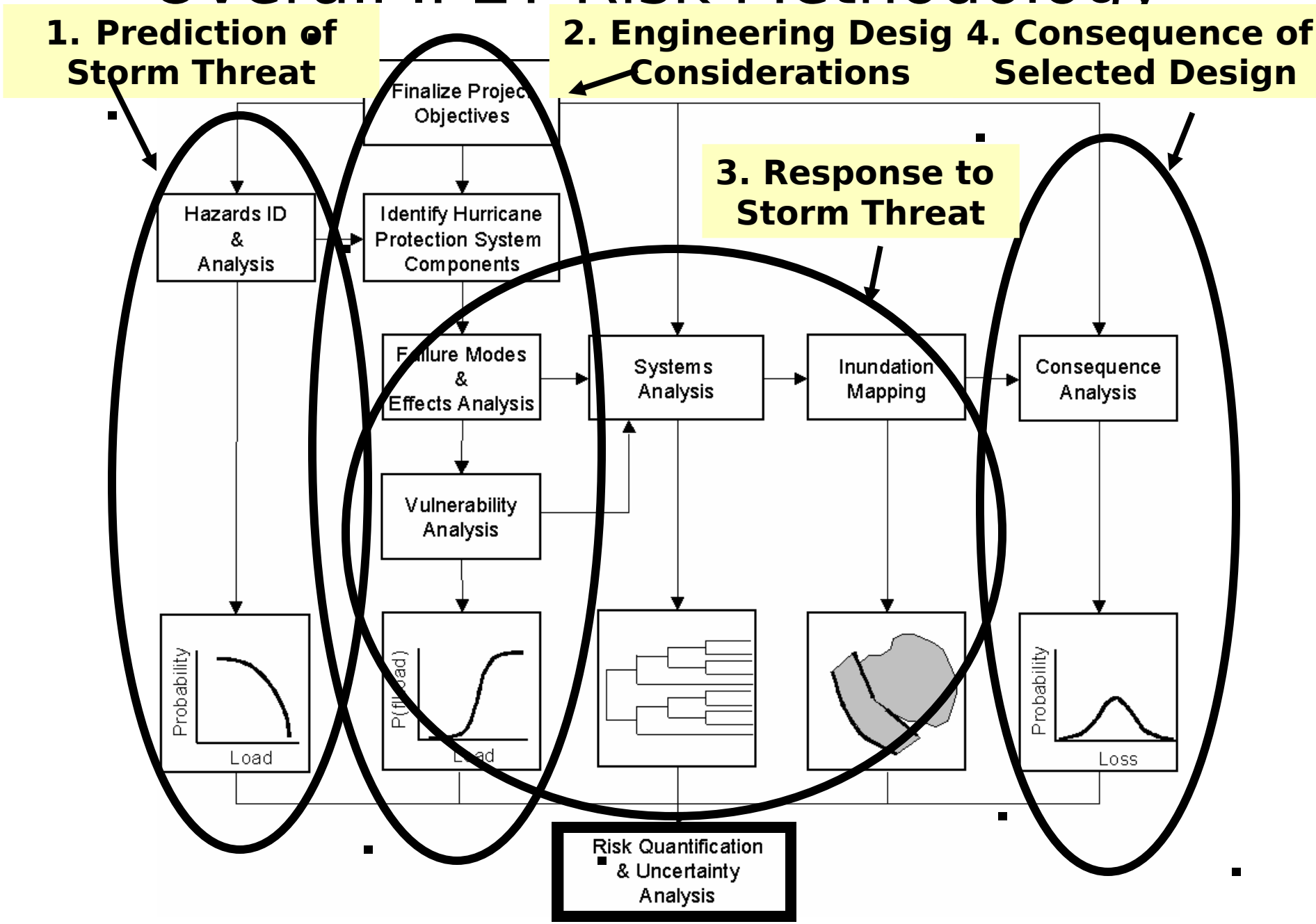
2. Wave contributions to surge could not be neglecte or treated within a simplified “surge-model-only” approach.

3. Hurricane Protection System must be a functionin system and not a disjoint set of structures.

4. Risk must be assessed probabilistically

5. Structural response must be treated via careful physics-based approach rather than empirical/ parametric methods.

Overall IPET Risk Methodology



RECENT EXPERIENCE:

IPET – Joint Probability Method (spatial sampling)

- **18000 storms reduced to only 2000 rough sc**
  - **and later to only about 600 fine scale r**
  - **but details were very crude**

EST/FEMA (local data + some smoothing of large storms)

- **Sampling size is such that 100-year values a**
  - **questionable for hurricanes.**
- **Should length of record be only factor consi**
  - **in plotting position for determining CD**
- **Given recognized climatic variability and hor**
  - **sampling prior to 1940's, why should e**
  - **data be included? This distorts the act**
  - **frequency of events from today's data.**
  - **might "help" in Katrina direct-hit area**
  - **will lead to severe under-prediction of**
  - **present risk in other areas.**

Example of Recent ADCIRC runs for New Orleans Area
46 historical storms selected – 42 runs passed QC (no key storms miss

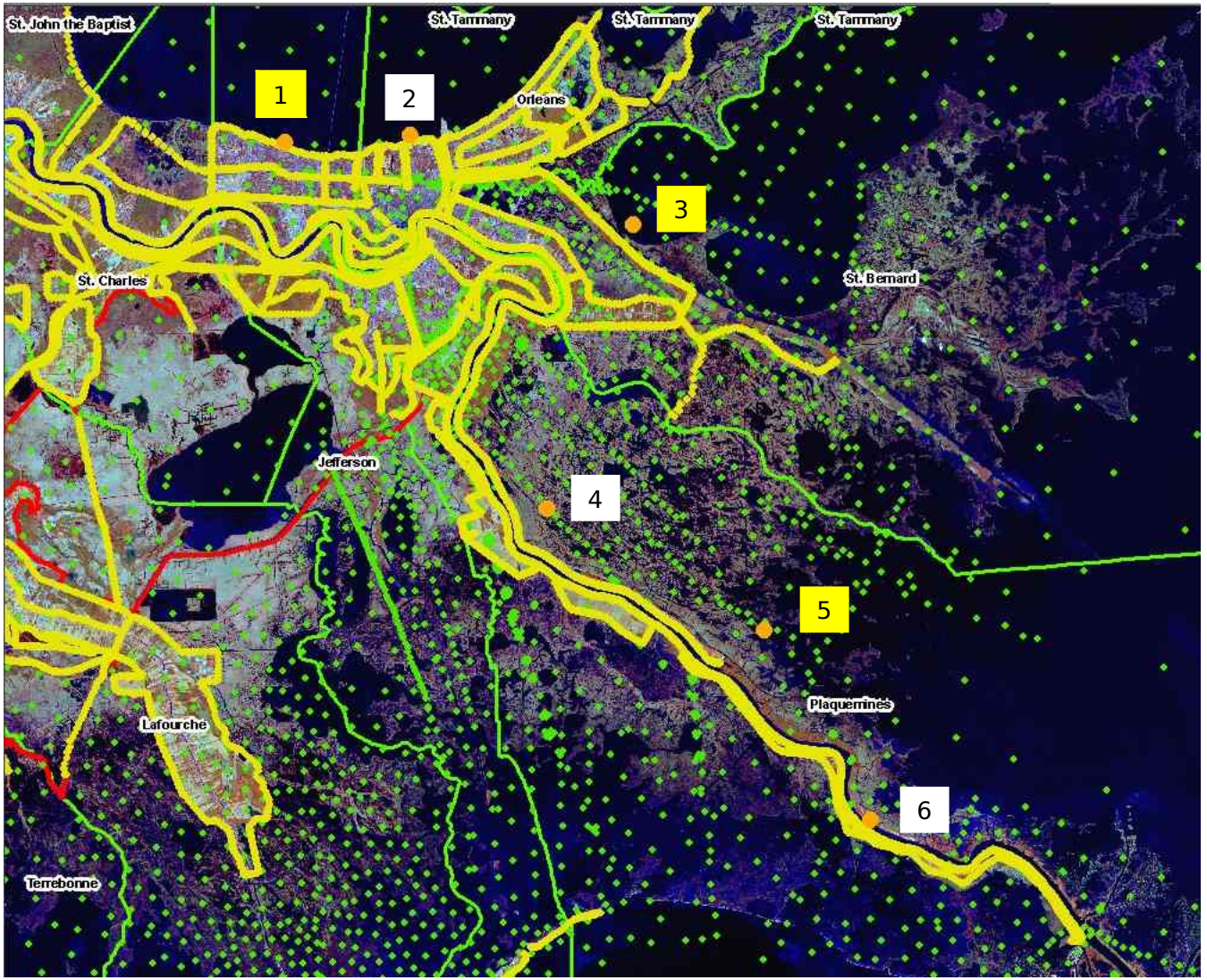
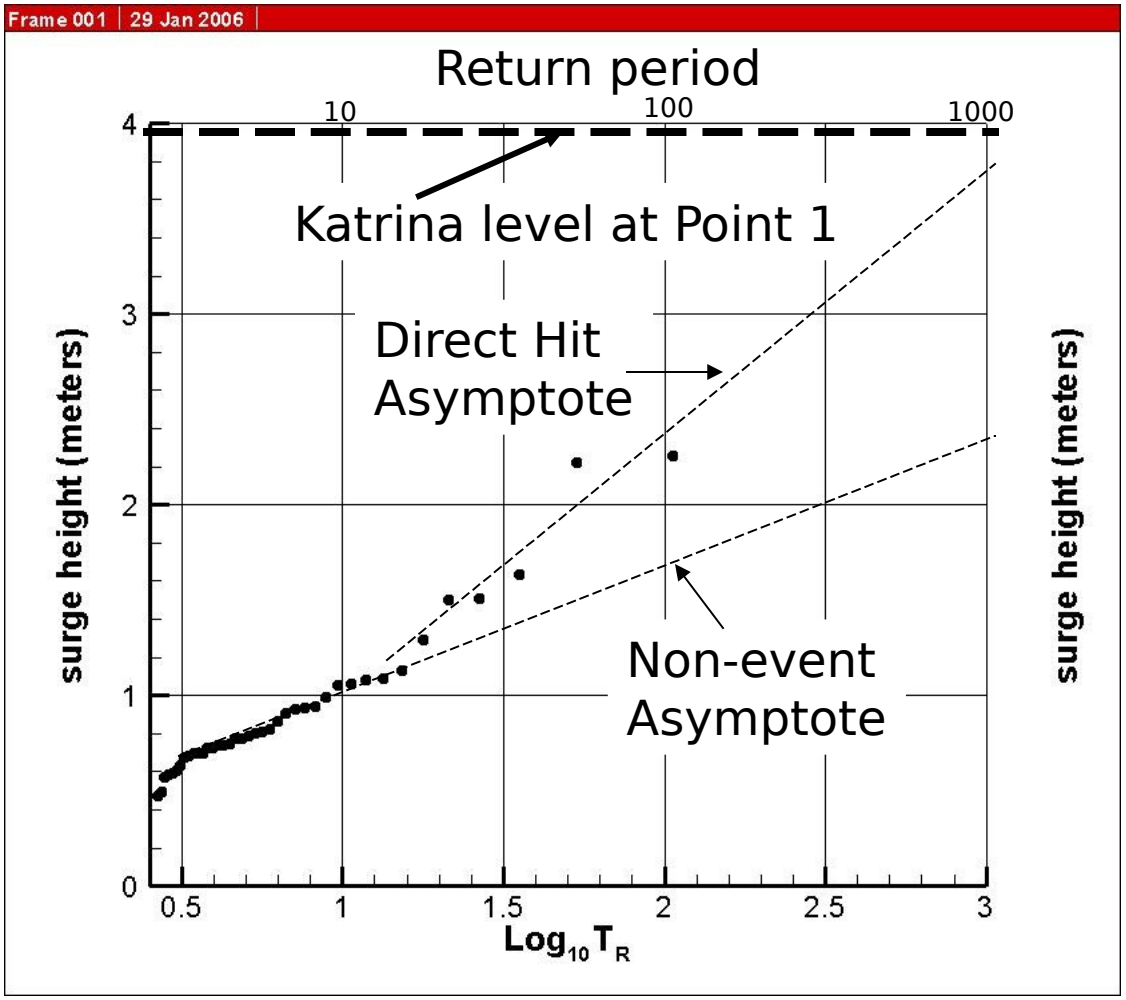


Figure shows points saved that will be discussed highlighted in yellow.

LOG Return Period Plot of ADCIRC Results

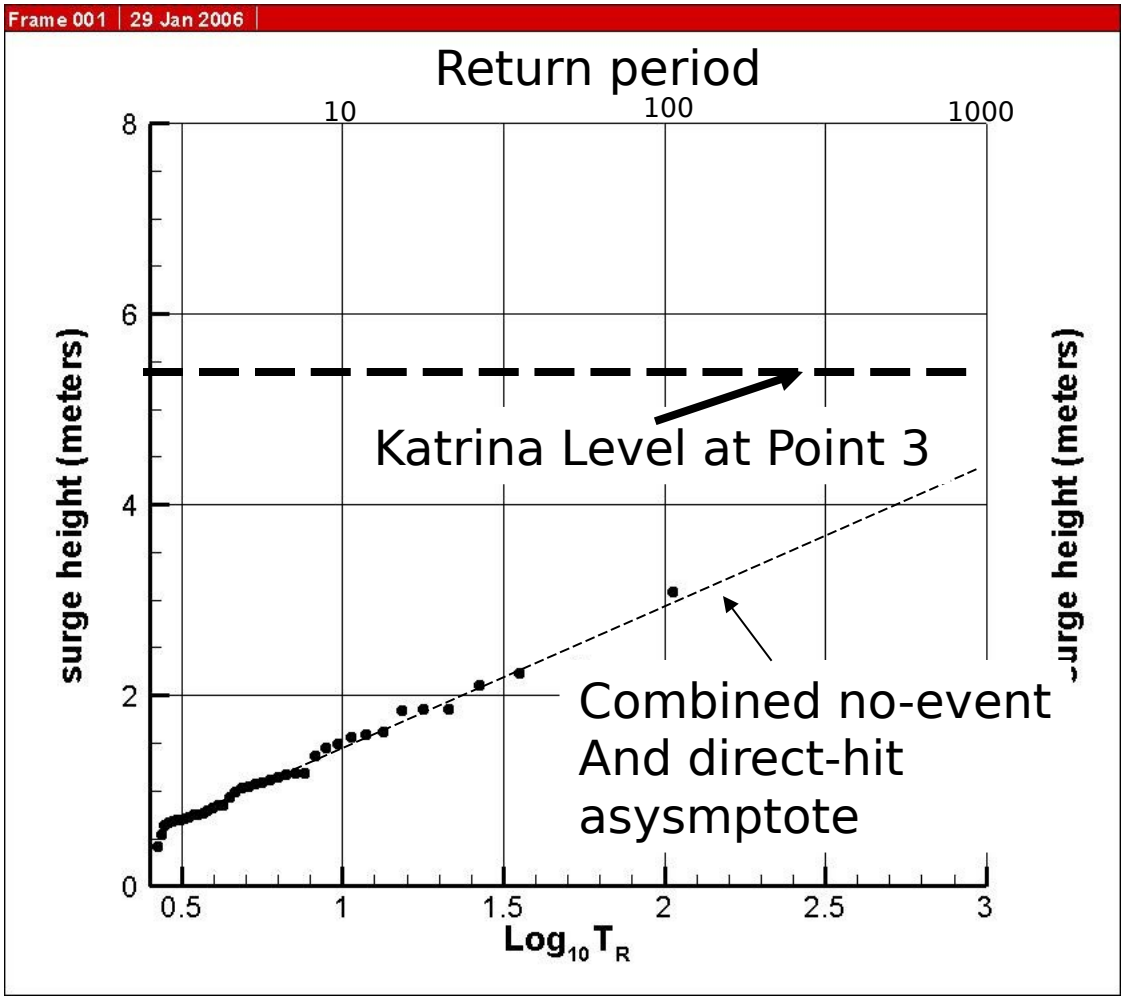
Point 1 (Lake Ponchartrain) – 2005 Hurricanes Removed



Results from FEMA simulations before 2005 storms are
dded show that Katrina may be a rare event for Lake Pontchartrain

LOG Return Period Plot of ADCIRC Results

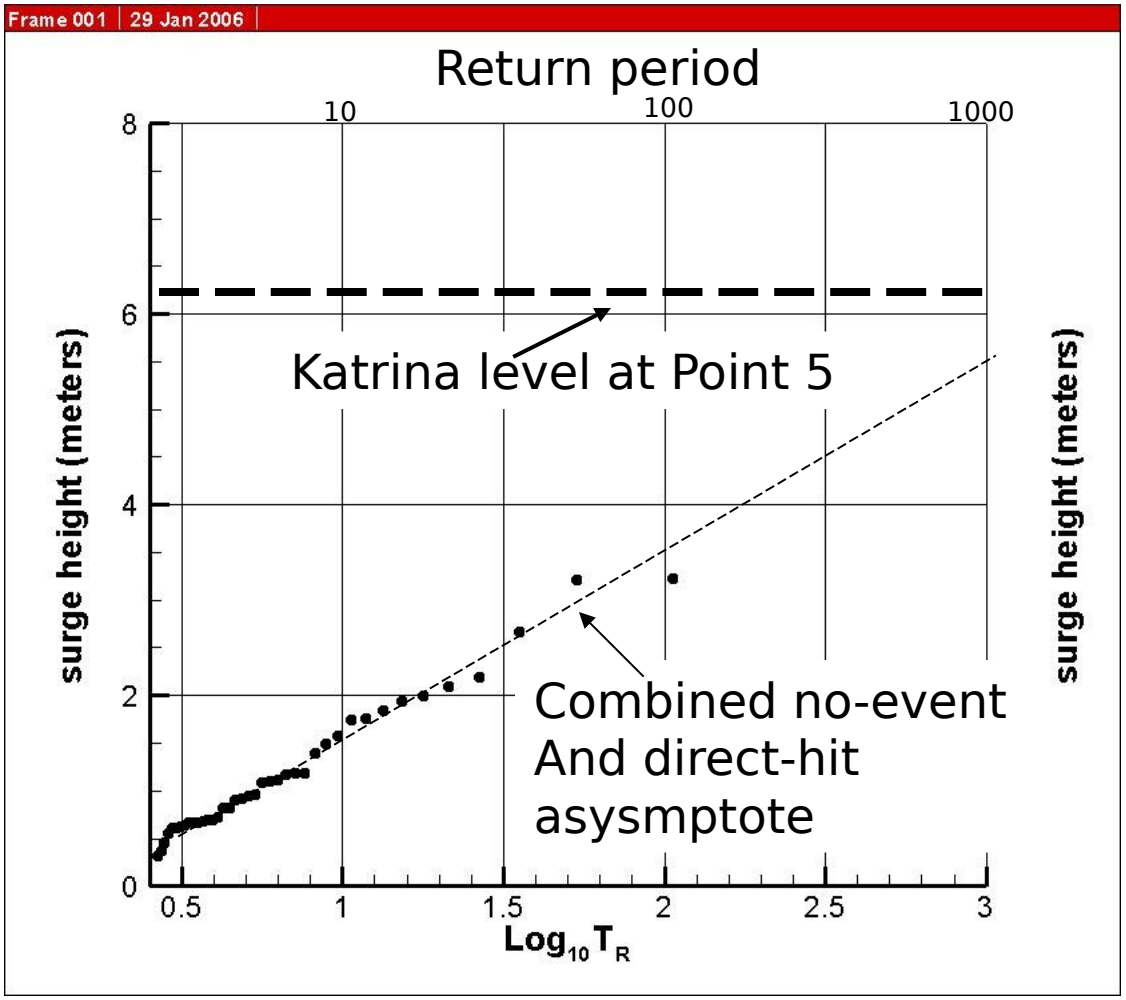
Point 3 (St Bernard Parish) – 2005 Hurricanes Removed



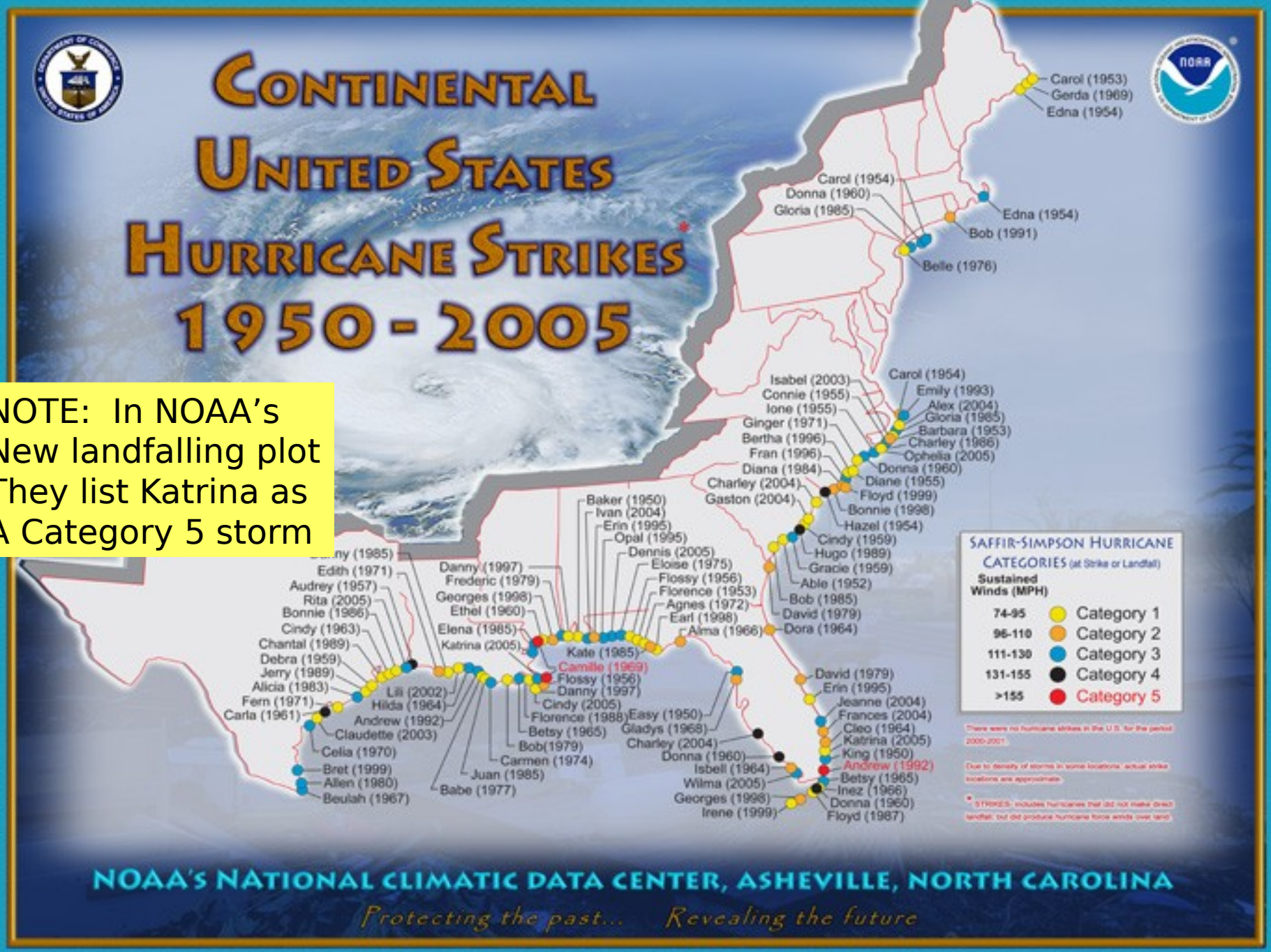
Results from FEMA simulations before 2005 storms are added show that Katrina may be a rare event for St Bernard Parish

LOG Return Period Plot of ADCIRC Results

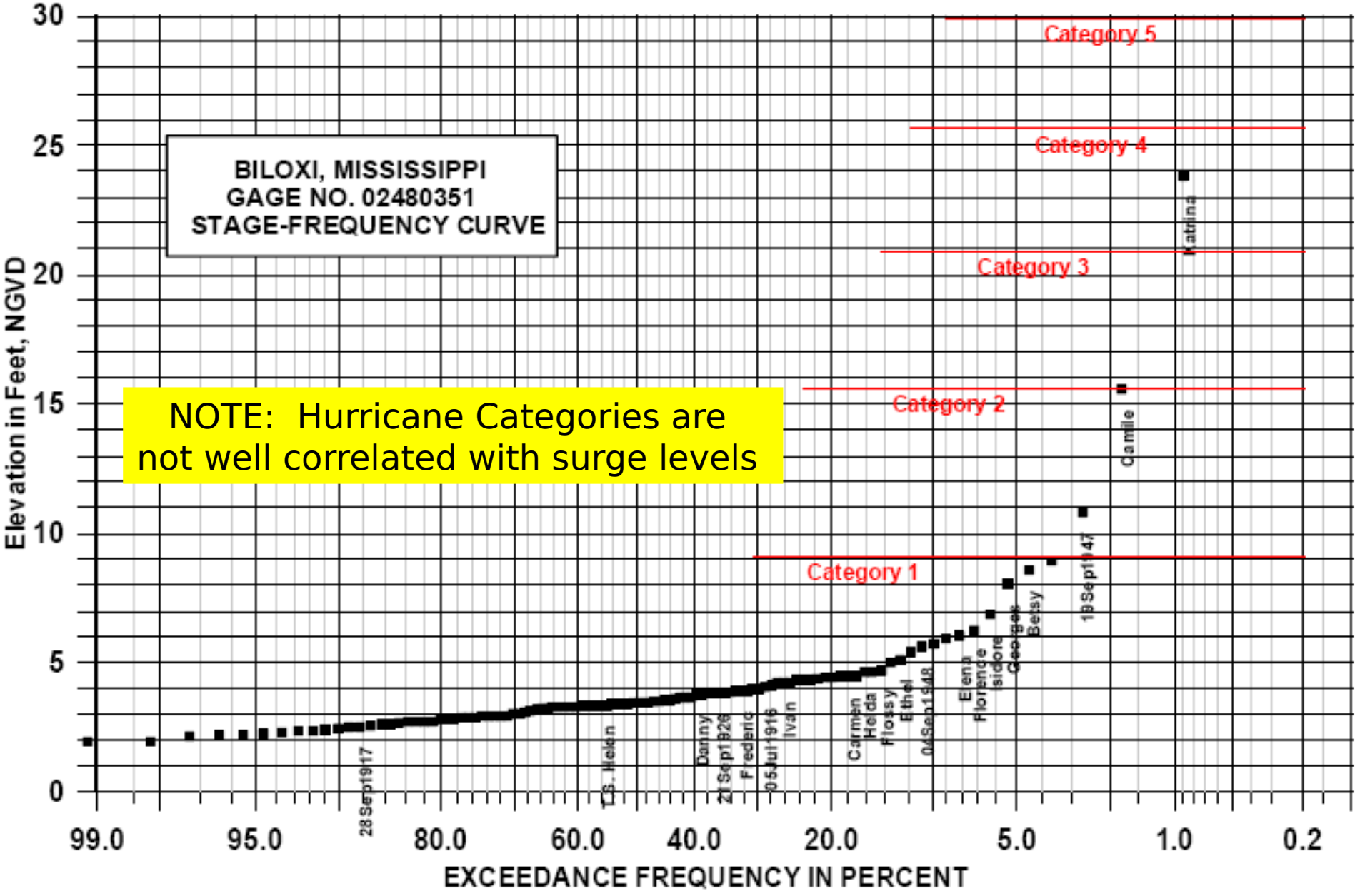
Point 6 (Plaquemines Parish) – 2005 Hurricanes Removed



Results from FEMA simulations before 2005 storms are
dded show that Katrina may be a rare event for Plaquemines Parish


CONTINENTAL
UNITED STATES
HURRICANE STRIKES
1950 - 2005
NOTE: In NOAA's
New landfalling plot
They list Katrina as
A Category 5 storm
SAFFIR-SIMPSON HURRICANE
CATEGORIES (at Strike or Landfall)
Sustained
Winds (MPH)
74-95 Category 1
96-110 Category 2
111-130 Category 3
131-155 Category 4
>155 Category 5
Carol (1953)
Gerda (1969)
Edna (1954)
Carol (1954)
Donna (1960)
Gloria (1985)
Edna (1954)
Bob (1991)
Belle (1976)
Isabel (2003)
Connie (1955)
Ione (1955)
Ginger (1971)
Bertha (1996)
Fran (1996)
Diana (1984)
Charley (2004)
Gaston (2004)
Carol (1954)
Emily (1993)
Alex (2004)
Gloria (1985)
Barbara (1953)
Charley (1986)
Ophelia (2005)
Donna (1960)
Diane (1955)
Floyd (1999)
Bonnie (1998)
Hazel (1954)
Cindy (1959)
Hugo (1989)
Gracie (1959)
Able (1952)
Bob (1985)
David (1979)
Dora (1964)
Baker (1950)
Ivan (2004)
Erin (1995)
Opal (1995)
Dennis (2005)
Eloise (1975)
Flossy (1956)
Florence (1953)
Agnes (1972)
Earl (1998)
Alma (1966)
Danny (1997)
Frederic (1979)
Georges (1998)
Ethel (1960)
Elena (1985)
Katrina (2005)
Kate (1985)
Camille (1969)
Flossy (1956)
Danny (1997)
Cindy (2005)
Florence (1988)
Betsy (1965)
Bob(1979)
Carmen (1974)
Juan (1985)
Babe (1977)
Easy (1950)
Gladys (1968)
Charley (2004)
Donna (1960)
Isbell (1964)
Wilma (2005)
Georges (1998)
Irene (1999)
David (1979)
Erin (1995)
Jeanne (2004)
Frances (2004)
Cleo (1964)
Katrina (2005)
King (1950)
Andrew (1992)
Betsy (1965)
Inez (1966)
Donna (1960)
Floyd (1987)
Edith (1971)
Audrey (1957)
Rita (2005)
Bonnie (1986)
Cindy (1963)
Chantal (1989)
Debra (1959)
Jerry (1989)
Alicia (1983)
Fern (1971)
Carla (1961)
Lili (2002)
Hilda (1964)
Andrew (1992)
Claudette (2003)
Celia (1970)
Bret (1999)
Allen (1980)
Beulah (1967)
NOAA'S NATIONAL CLIMATIC DATA CENTER, ASHEVILLE, NORTH CAROLINA
Protecting the past... Revealing the future

NOAA Historical Data Analysis with Hypothetical Category Impact Superimp



"Gage" is also HWM and Historical Information

PERIOD OF RECORD, 1882-2005

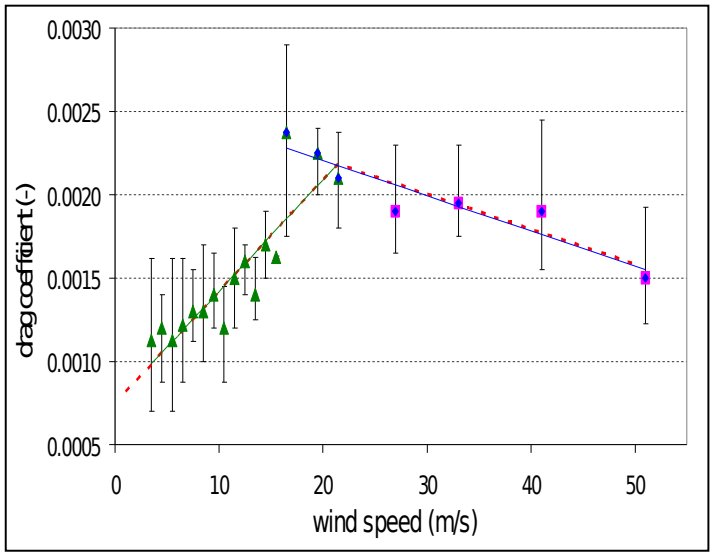
Characterization of Potential Surge Level In Hurricanes: Beyond the Saffir-Simpson Scale

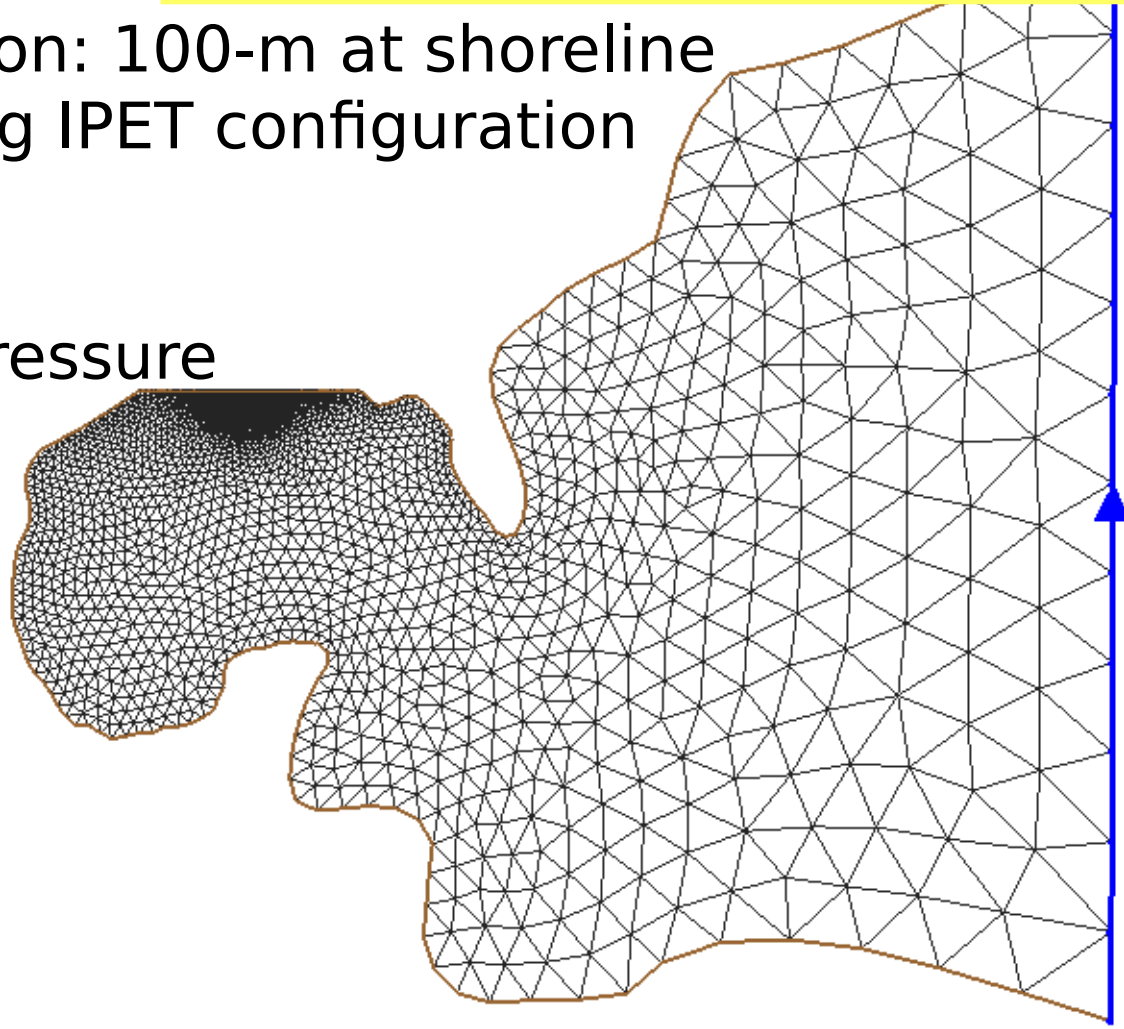
- Use calibrated ADCIRC with validated estimates of wi speeds
- Develop functional relationships that include effects o wind speed, storm size, forward speed of storm, characteristic slope of nearshore/slope region, and dis between site and location of peak surge
- Develop understanding of relationships between offsh hurricane characteristics and landfall characteristics

Storm Surge Characterization
Model Setup

NOTE: High wind behavior appears to b
equivalent to constant momentum flux
This has critical implications for surges

- ADCIRC
  - Finite element
  - Variable resolution: 100-m at shoreline
  - Calibration: using IPET configuration
  - Forcing:
    - Wind stress
    - Barometric pressure





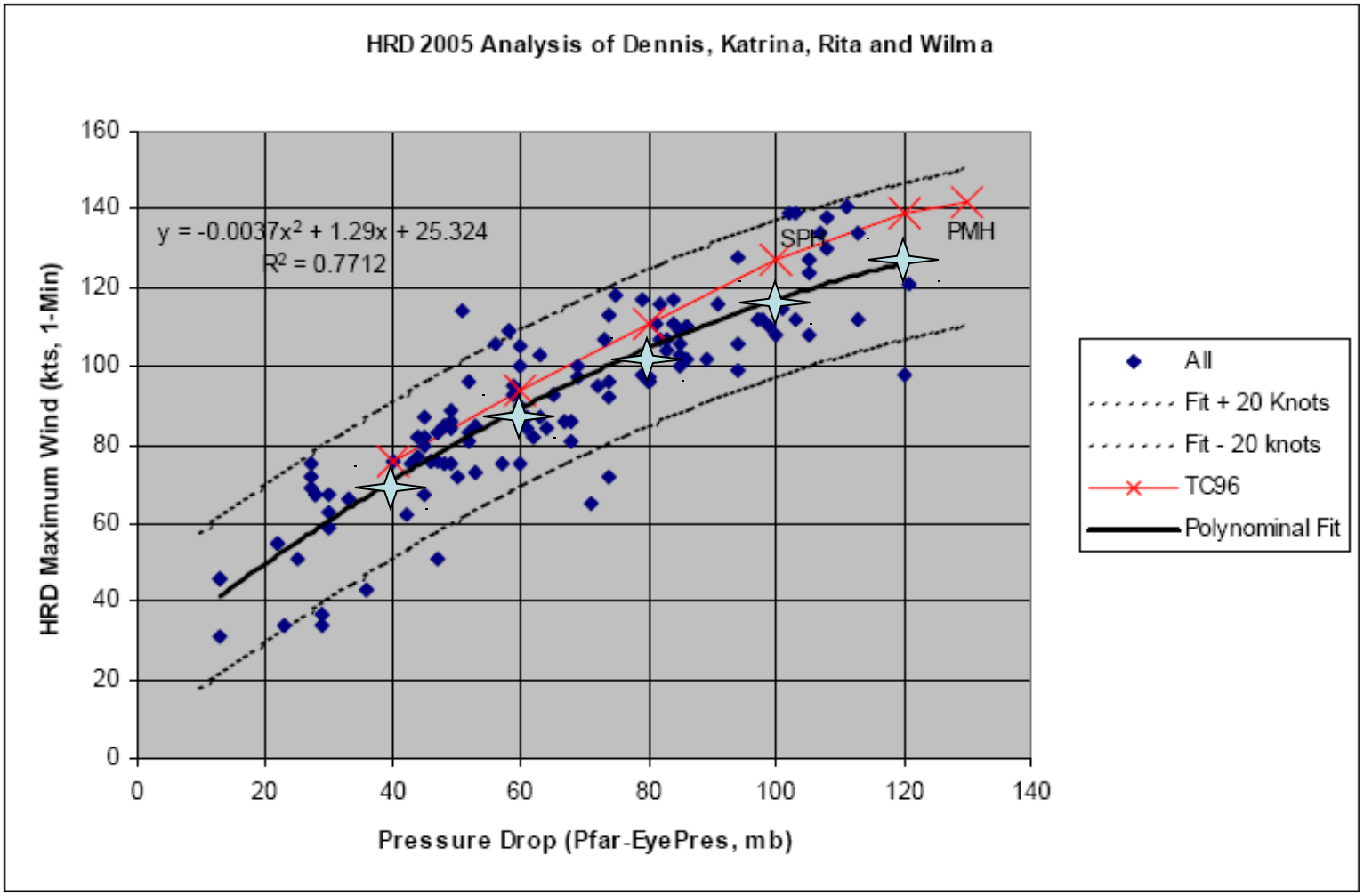
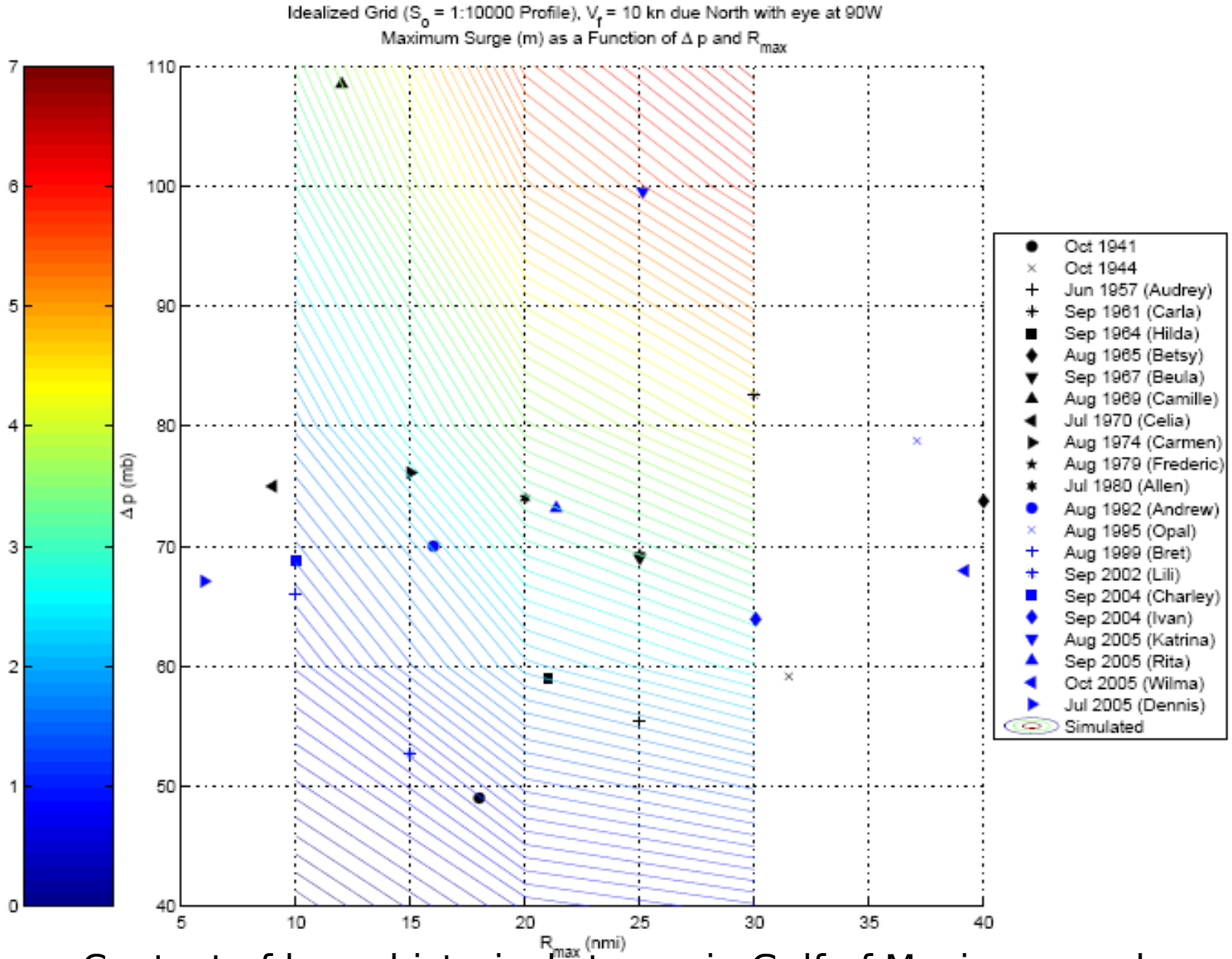


Figure 1. TC96 Maximum 1-minute wind (kts) solution compared with HWind 1-min maximum wind (kts) vs. pressure drop (mb)

$V_{max} = (V_f + (A\Delta p - B)^{1/2})x1.2$

Note: 1.2 factor converts from 1-min max to 30-min avera

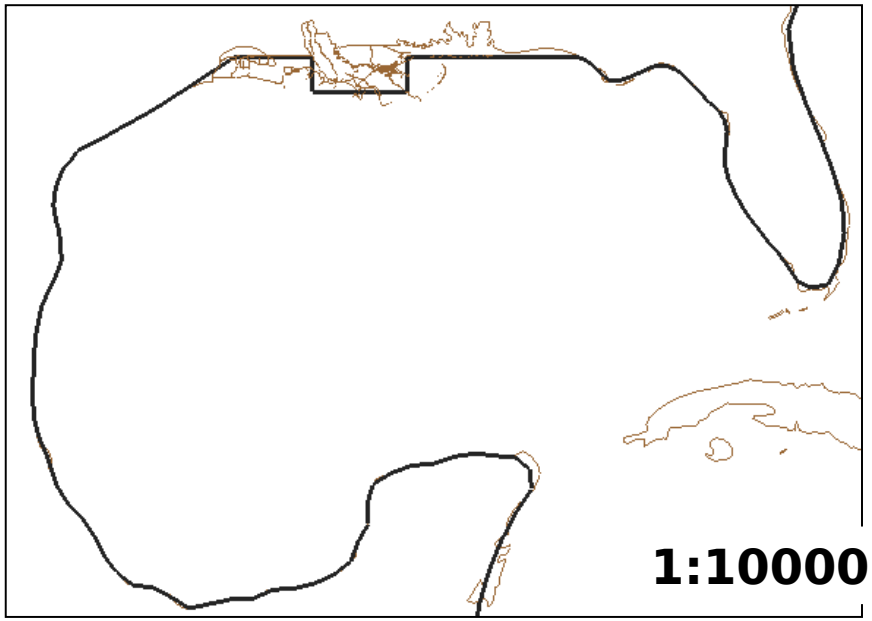
Constant Holland "B" seems ok for first Approximation.

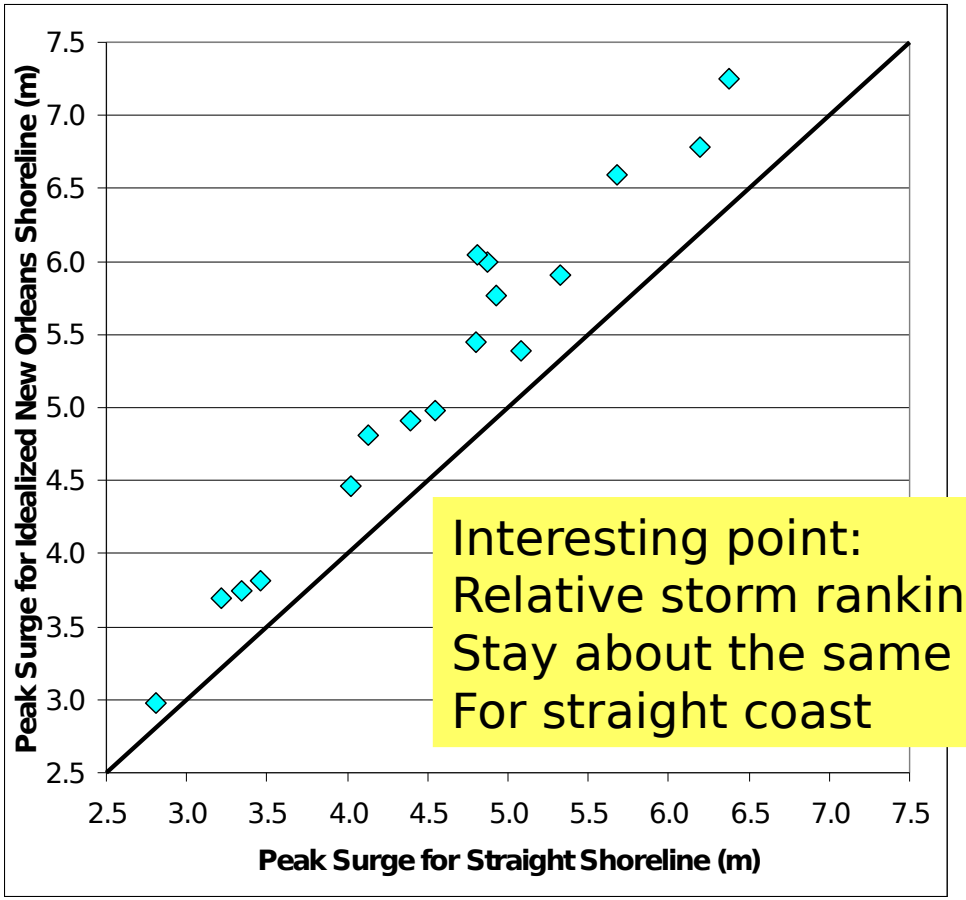


Context of large historical storms in Gulf of Mexico on a slope of 1:10,000

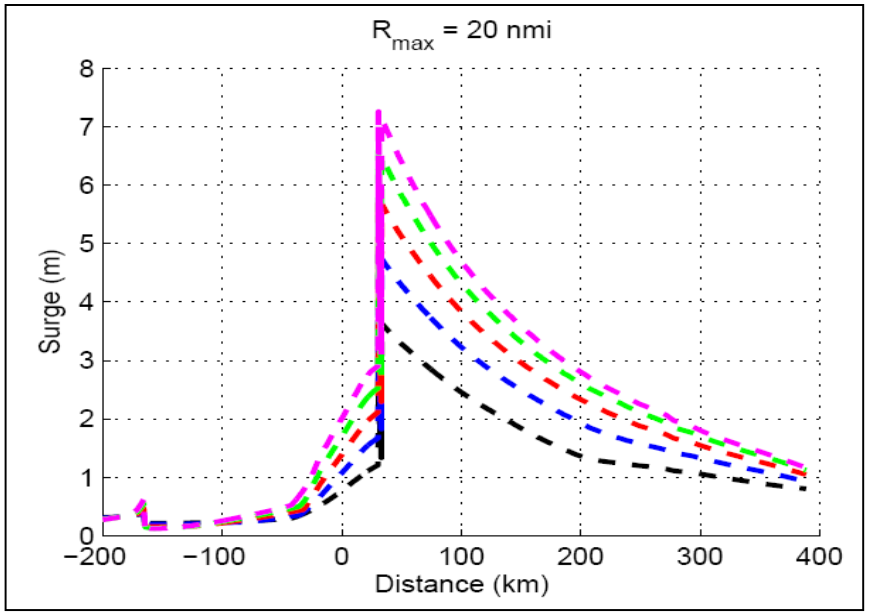
Storm Surge Characterization

Ongoing Work: Shoreline Features





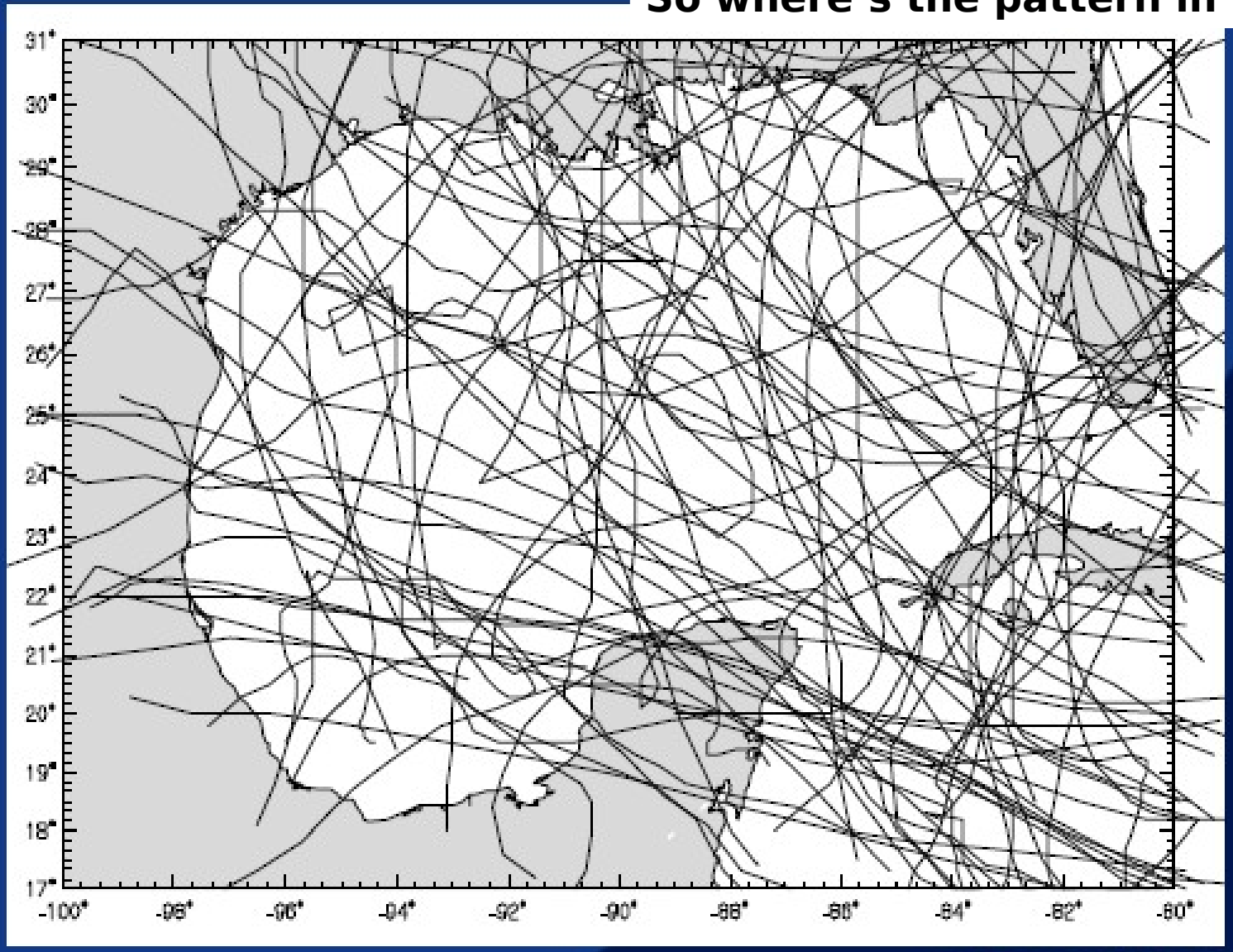
Interesting point:
Relative storm ranking
Stay about the same a
For straight coast

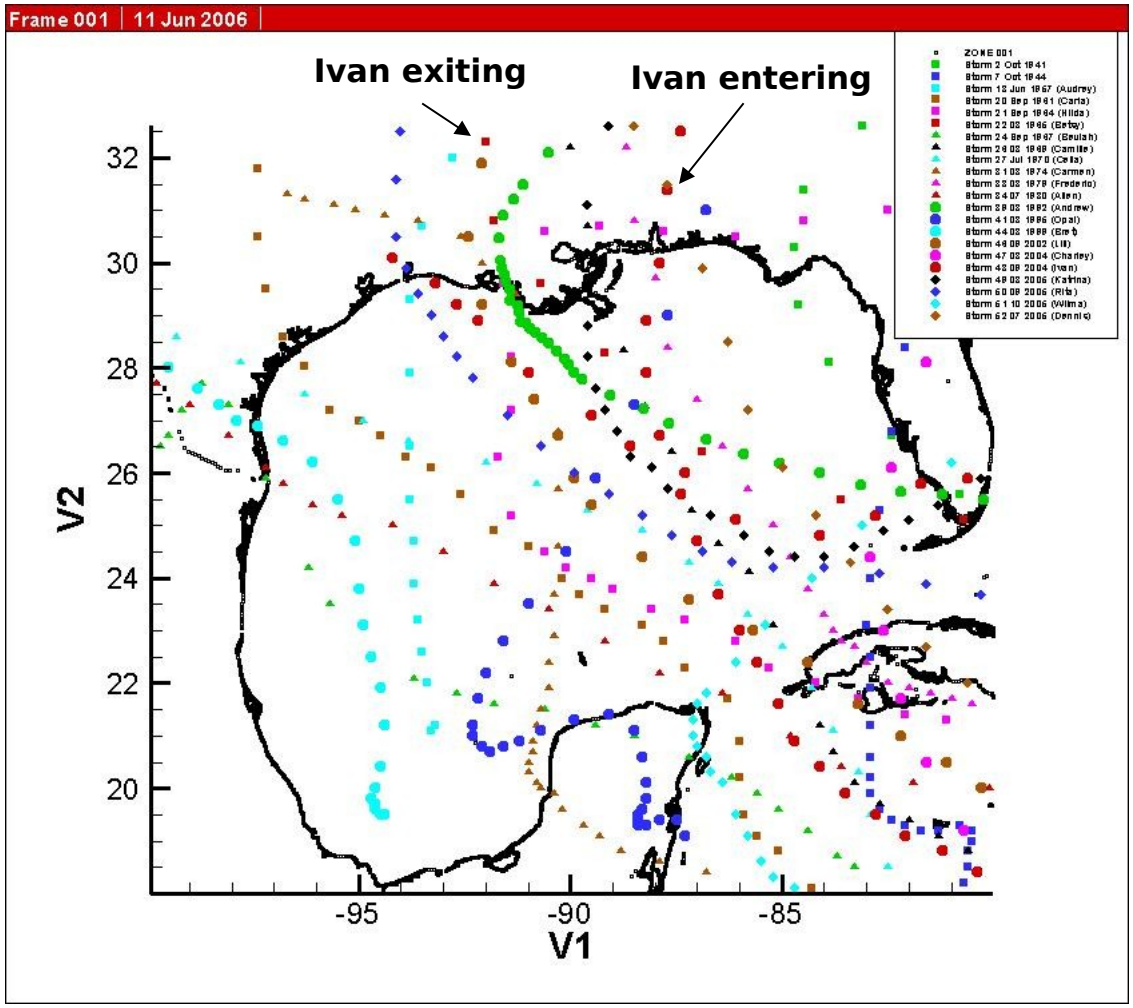


Peak surge ~ 10% larger in area with coastal shape as shown here.

Cat. 2 Candidate Track Map

So where's the pattern in this?





Tracks of all “major” (Cp in Gulf ≤ 955 mb) storms landfalling in Gulf of Mexic
1941-2005.

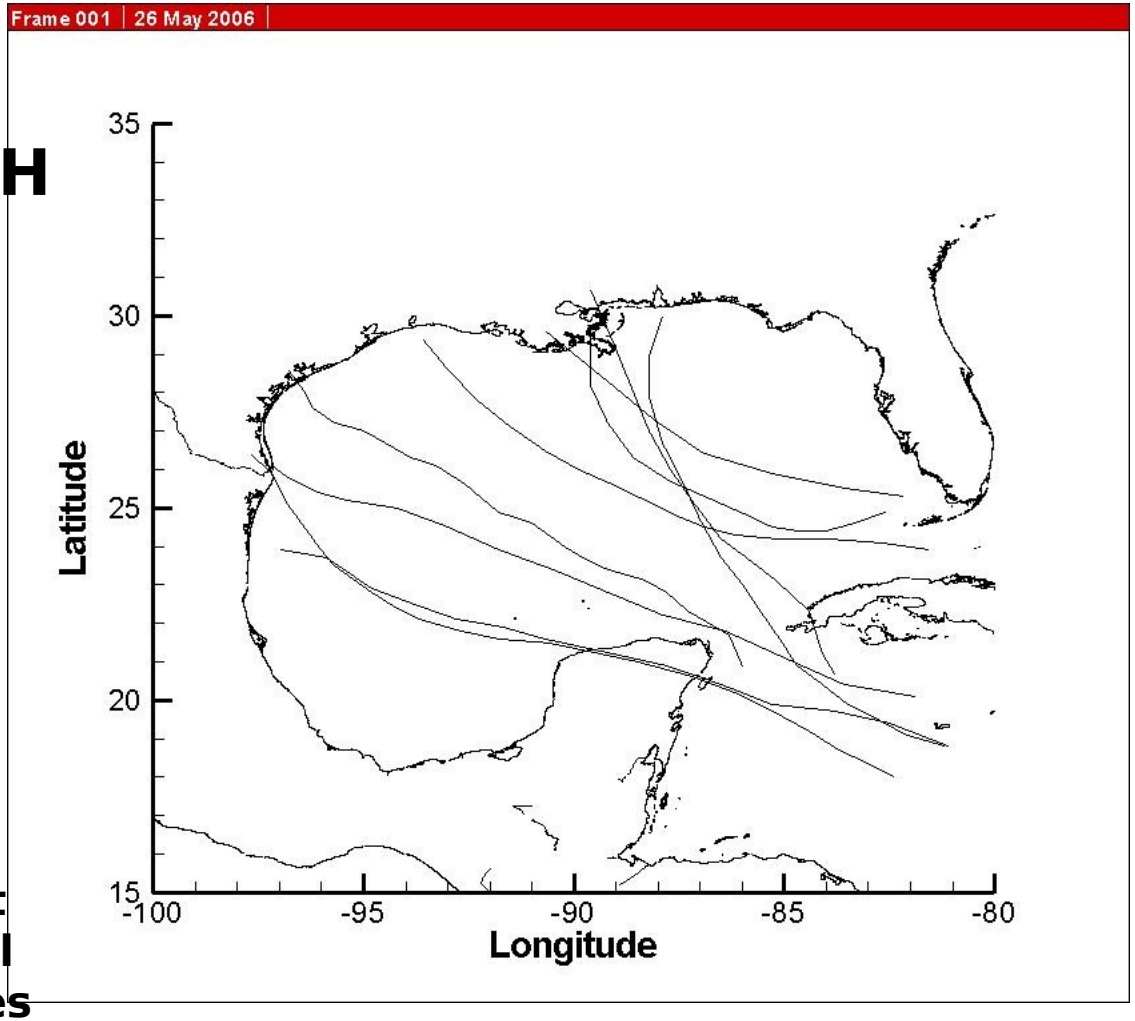
HURRICANE TRACKS FOR ALL STORM WITH VMAX ≥125 KTS

PHYSICAL CONSTRAINTS:

Land
Lack of Shear

Note:

Wilma, Charlie & Opal are west coast of Florida storms and will be under influence of westerlies



Given that there are only 6-9 strong storms in the record, isn't cutting this into 18000 slices for the cutting the sample a bit thin?

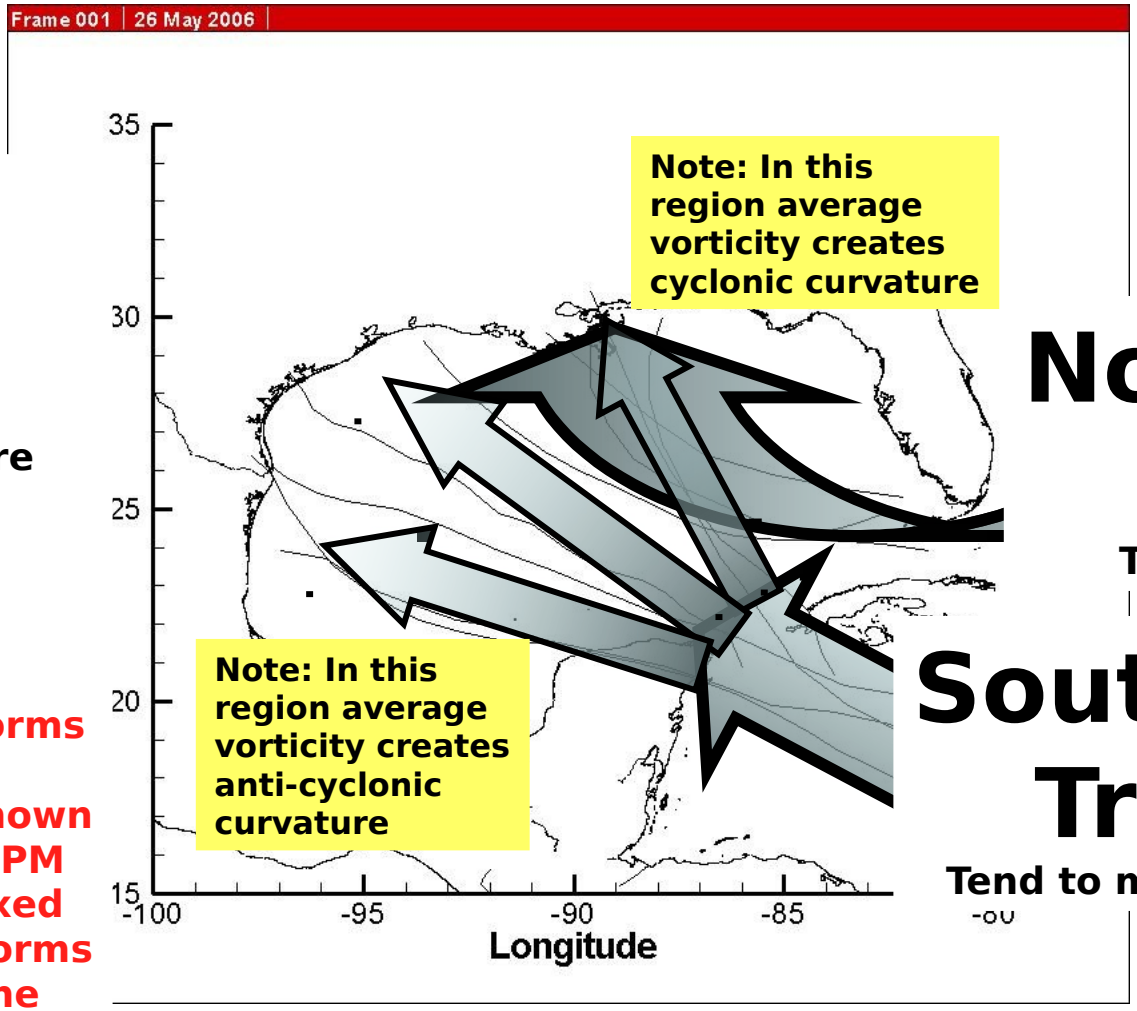
TWO PRIMARY "OVER-WATER" ROUTES INTO THE GULF OF MEXICO

These doors are wide open when the steering currents in the atmosphere and lack of shear in the Caribbean are in correct phase

+

A warm Gulf of Mexico

NOTE: Small storms follow different patterns than shown here. Previous JPM studies have mixed small & large storms together to define angles of approach.



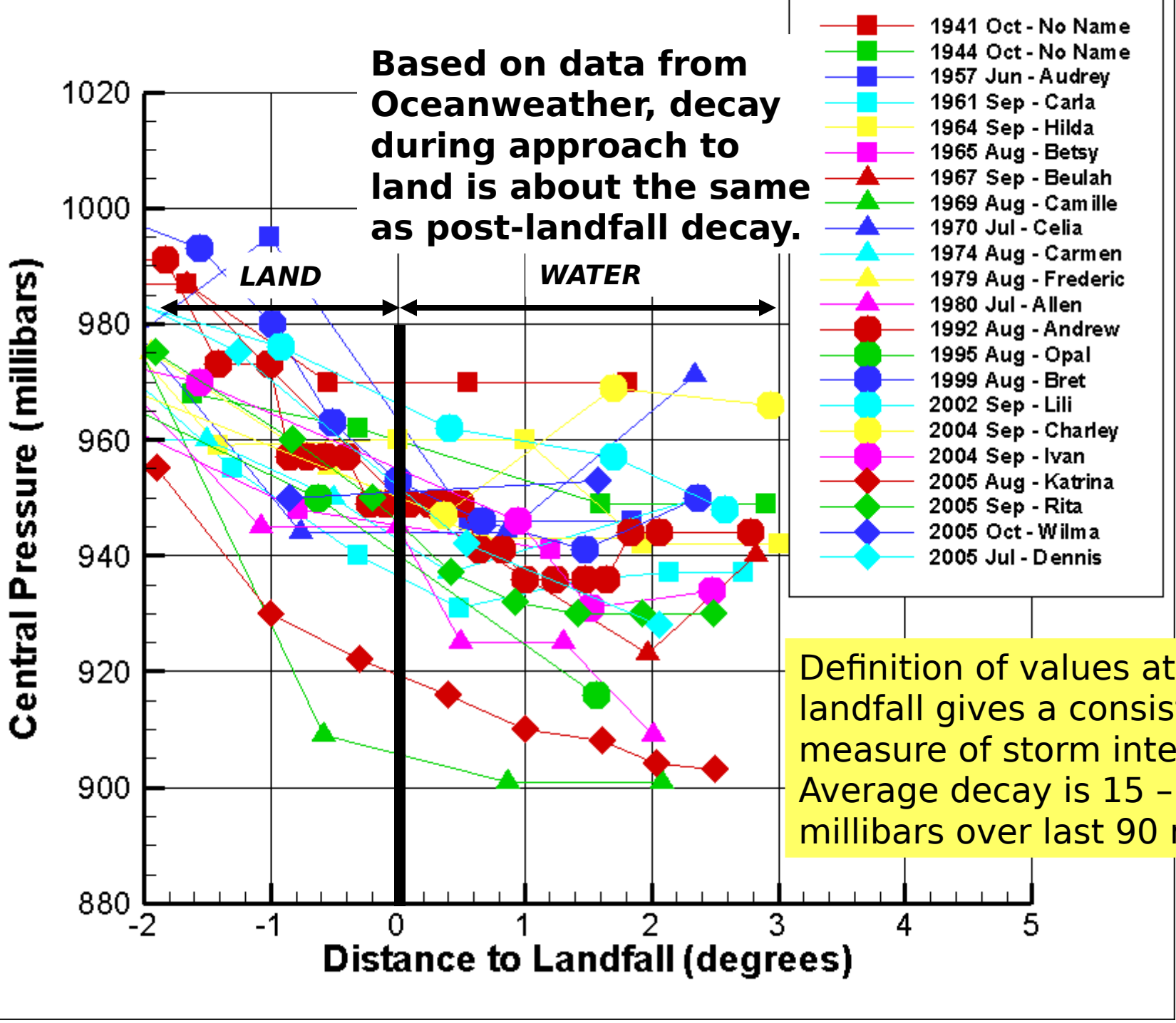
Northern Track

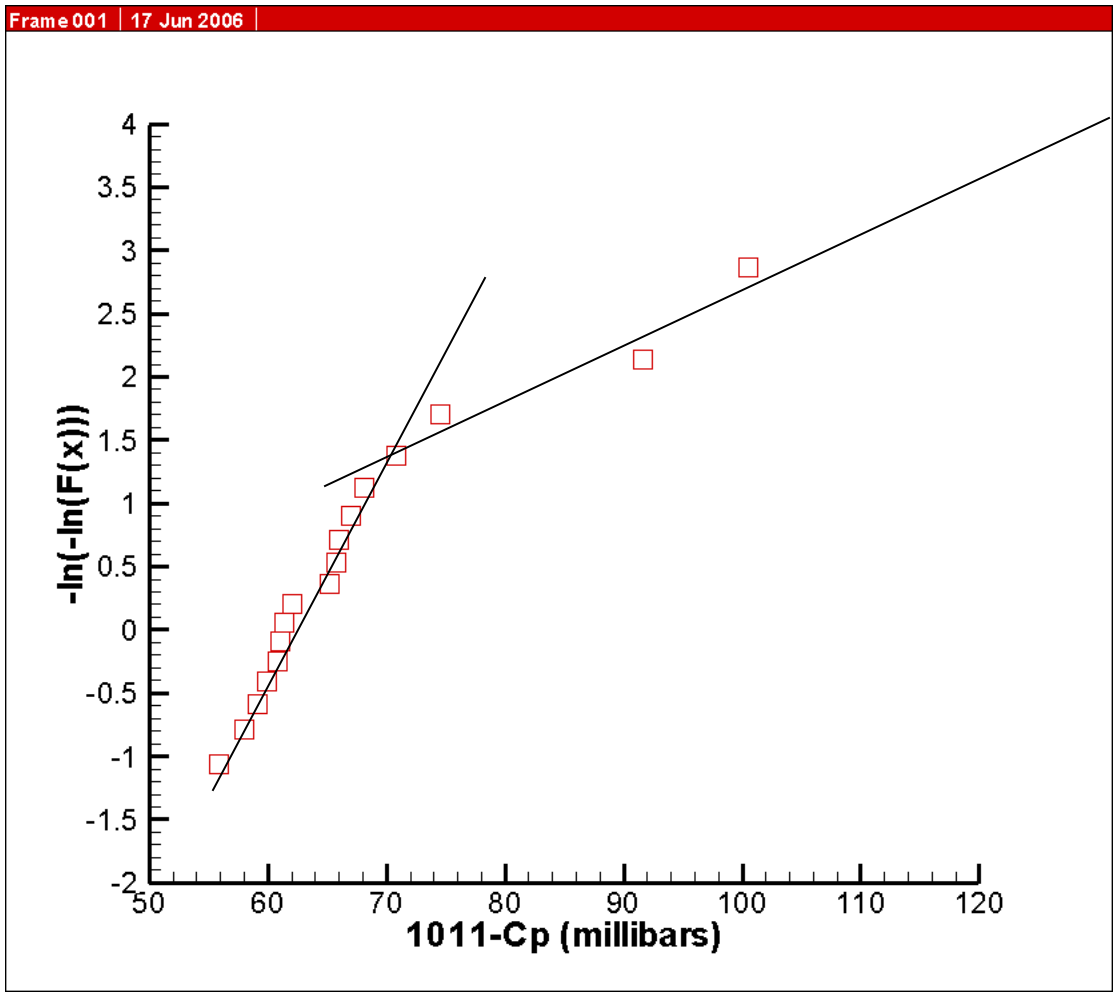
Tend to recurve

Southern Track

Tend to move straight

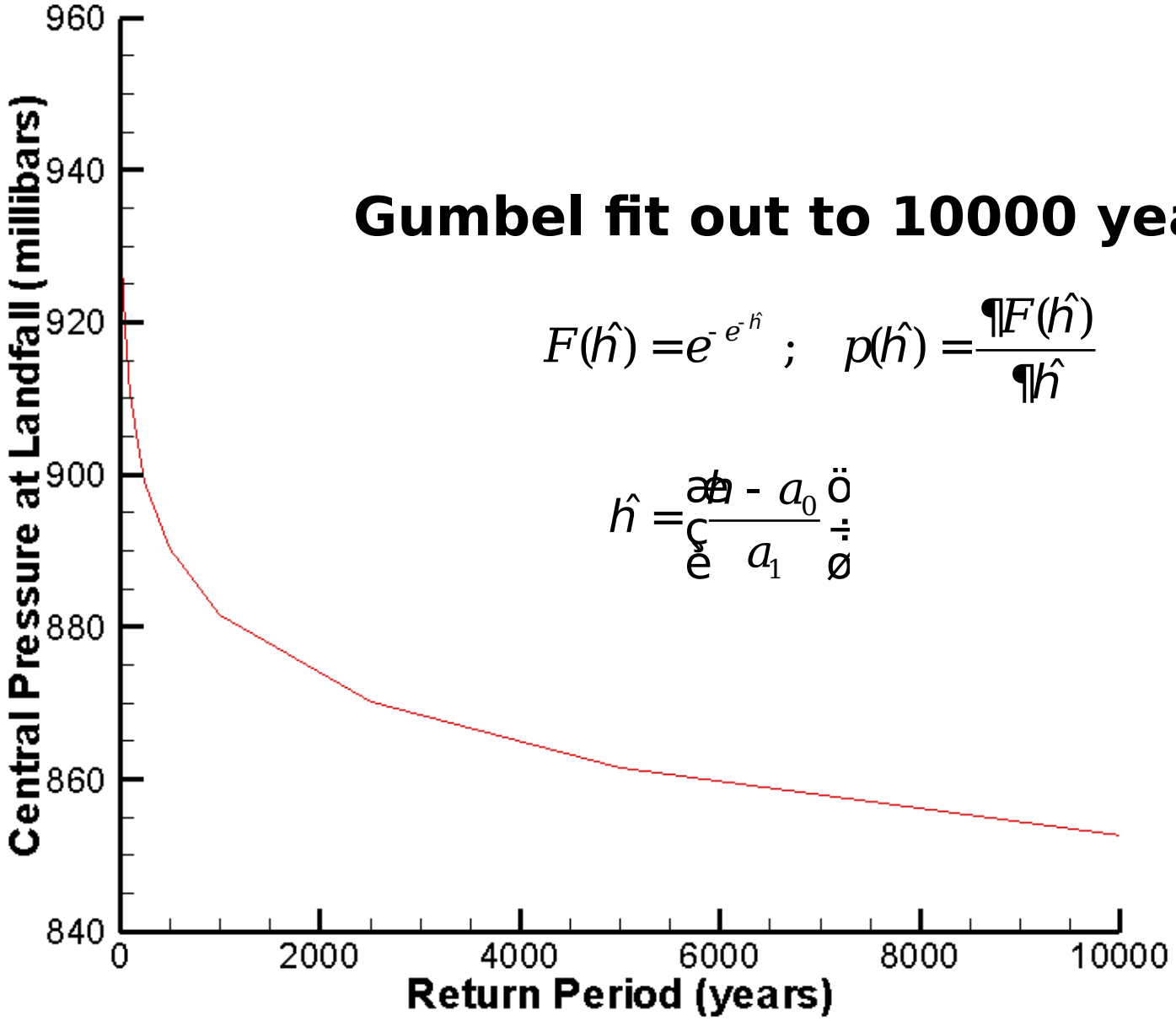
NOTE: These storms are not as curved as weaker storms since they are less c by extratropical influences. Also, statistics will likely be Gulf specific


Based on data from Oceanweather, decay during approach to land is about the same as post-landfall decay.
LAND
WATER
Central Pressure (millibars)
Distance to Landfall (degrees)
1020
1000
980
960
940
920
900
880
-2
-1
0
1
2
3
4
5
1941 Oct - No Name
1944 Oct - No Name
1957 Jun - Audrey
1961 Sep - Carla
1964 Sep - Hilda
1965 Aug - Betsy
1967 Sep - Beulah
1969 Aug - Camille
1970 Jul - Celia
1974 Aug - Carmen
1979 Aug - Frederic
1980 Jul - Allen
1992 Aug - Andrew
1995 Aug - Opal
1999 Aug - Bret
2002 Sep - Lili
2004 Sep - Charley
2004 Sep - Ivan
2005 Aug - Katrina
2005 Sep - Rita
2005 Oct - Wilma
2005 Jul - Dennis
Definition of values at landfall gives a consistent measure of storm intensity! Average decay is 15 – 20 millibars over last 90 nm.



Gumbel plot suggests that, out of set of 22 storms, the largest 4 storms may represent a different population.

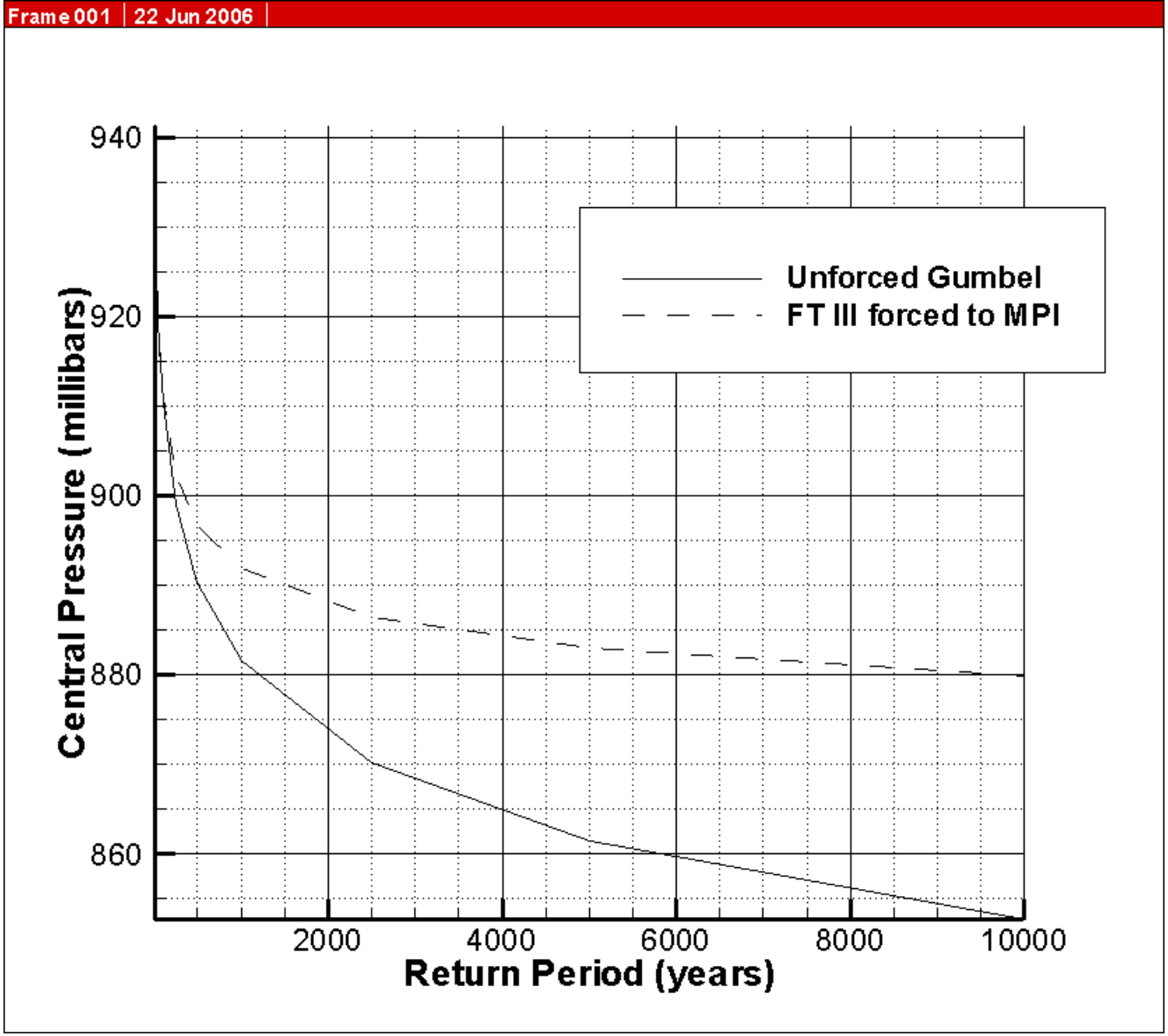
Plot of the cumulative distribution function for pressu difference from peripheral pressure (1011-Cp) versus essure difference from peripheral pressure for all sto at landfall.



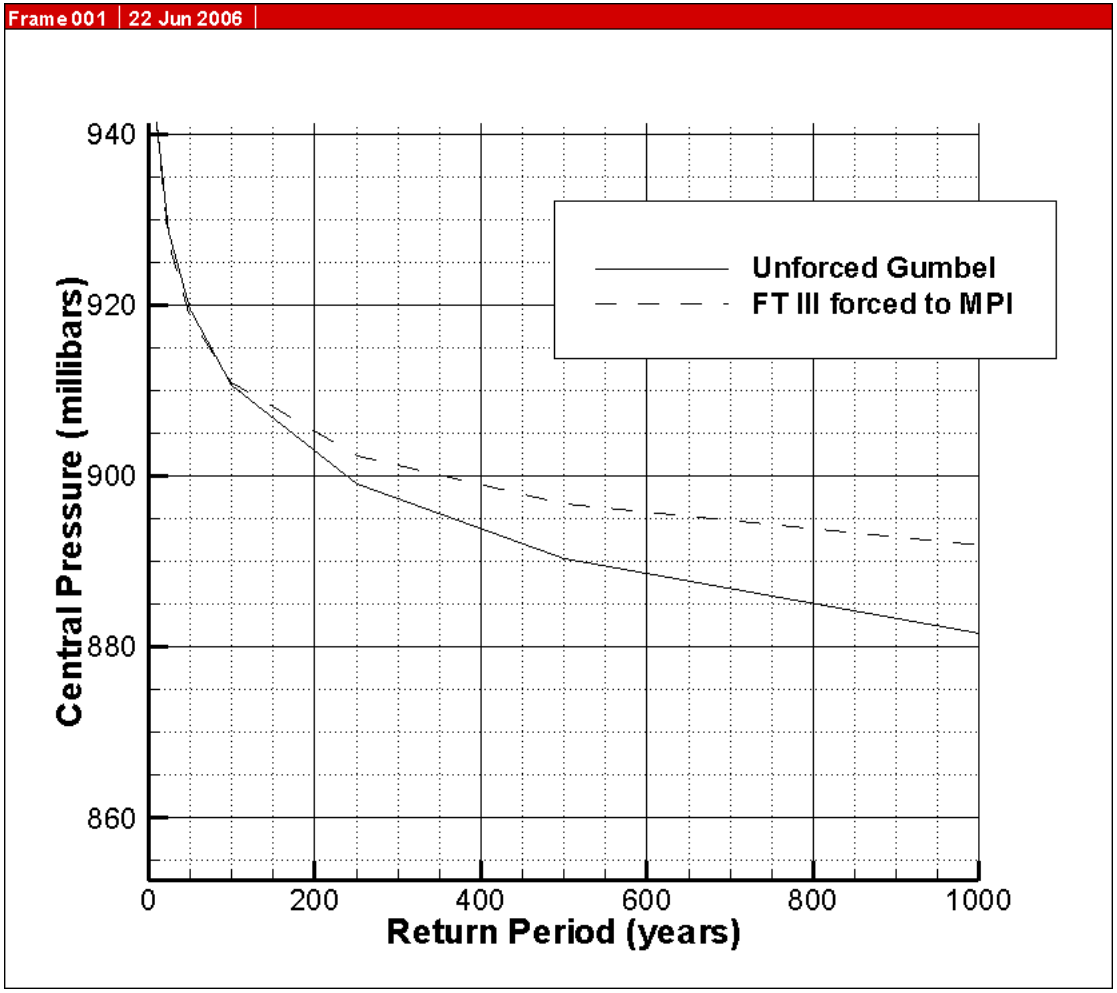
Gumbel fit out to 10000 years

$$F(\hat{h}) = e^{-e^{-\hat{h}}} \quad ; \quad p(\hat{h}) = \frac{\partial F(\hat{h})}{\partial \hat{h}}$$

$$\hat{h} = \left(\frac{p - a_0}{a_1} \right)$$



Solving for the inverse GEV function such that the limit is equal to the MPI v
of approximately 880 mb at 10000 years yields the solution shown here, wit
Generalized GEV form given by $\hat{h} = b_0 + b_1 \left(\frac{1 - e^{-b_2 h}}{b_2} \right)$



Same as previous derivation except that curve is only shown out to 1000 y

We have shown that as a good approximation the peak surge can be writ
Terms of a set a 4 parameters, holding the Holland "B" term constant, at
for relative ranking:

$$h_p = F(\Delta p, R_{max}, V_{ff}, \alpha)$$

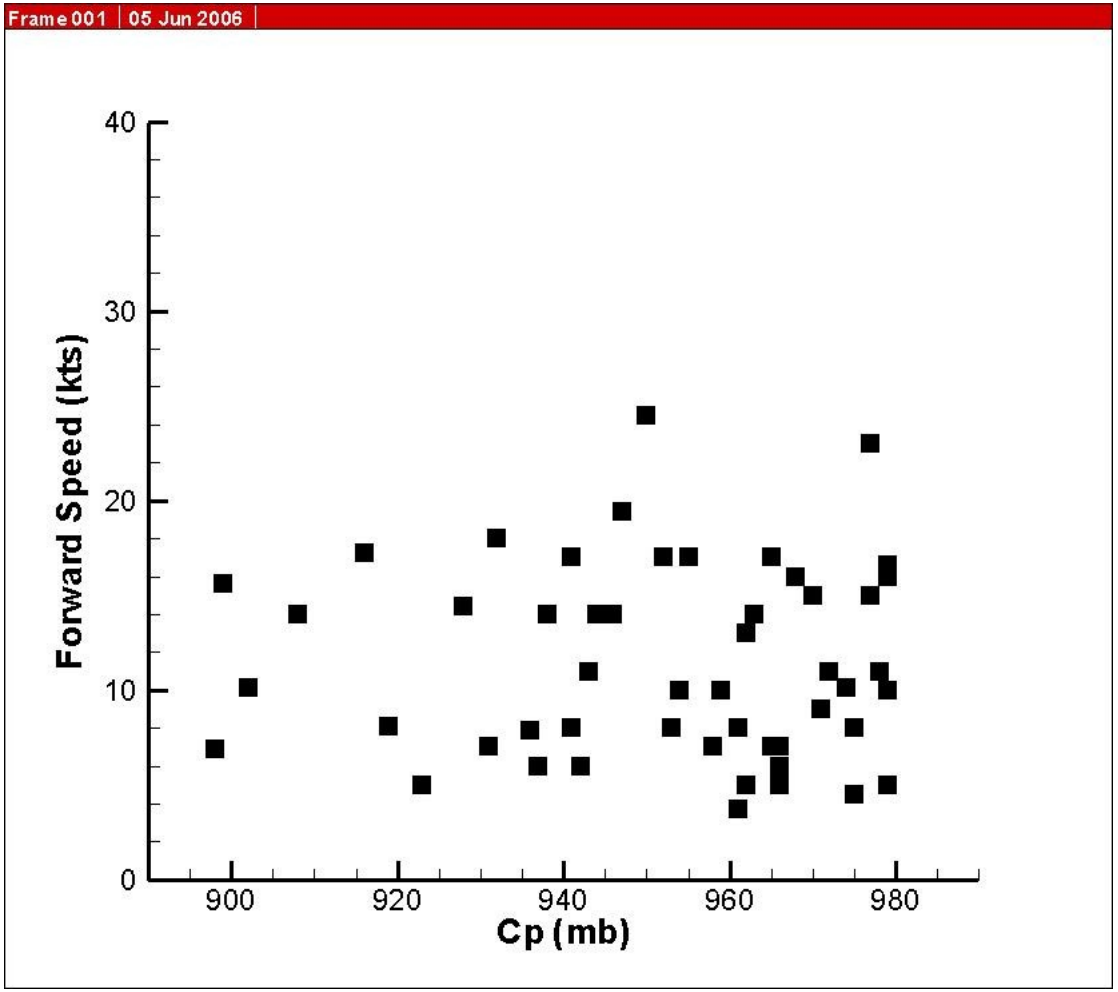
where α_f is the track angle relative to the coast. The probability of h_p is

$$p(h_p) = \iiint p(\Delta p, R_{max}, V_{ff}, \alpha)\,\delta[h_p - F(\Delta p, R_{max}, V_{ff}, \alpha)]\,d\Delta p\,dR_{max}\,dV_{ff}\,d\alpha$$

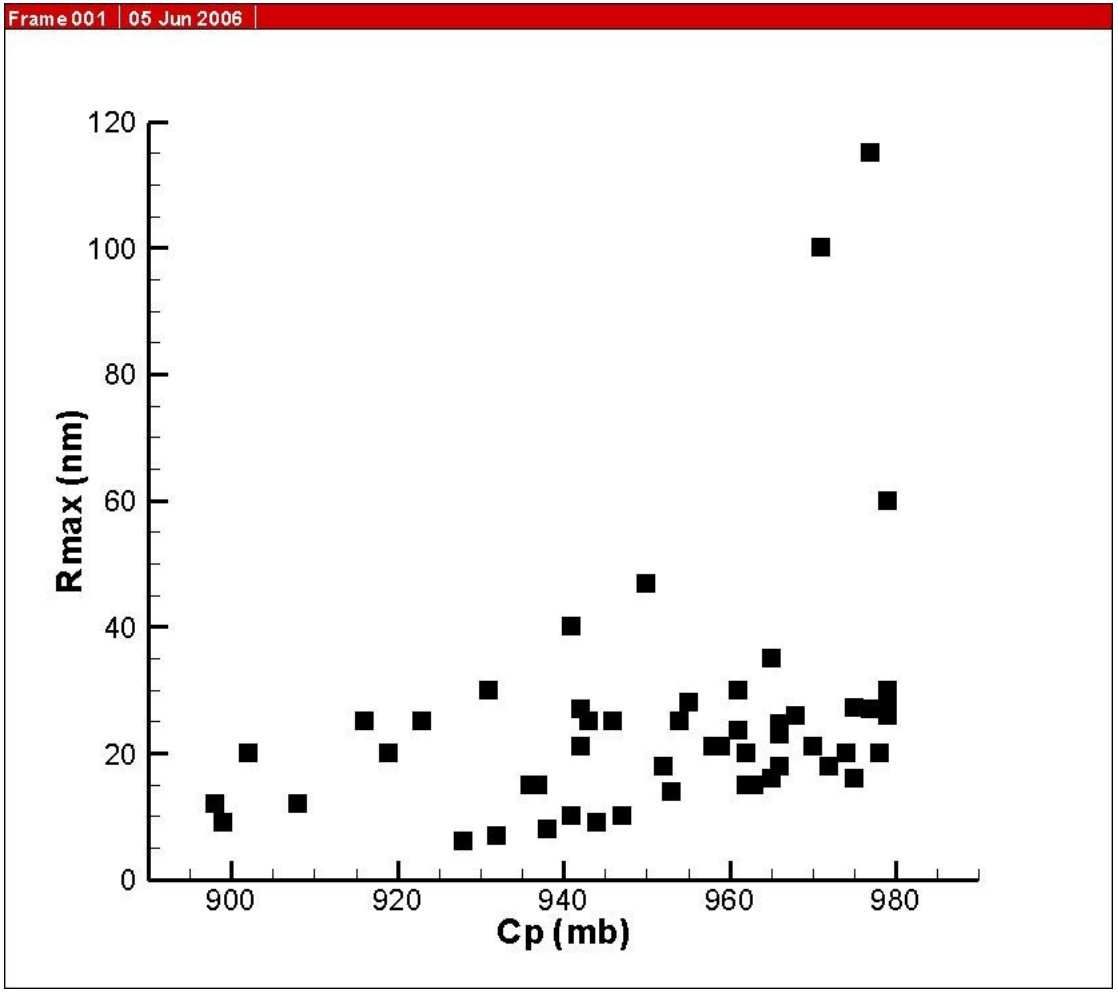
where $\delta[x]$ is the Dirac delta function {$\delta[x]=1$ for $x=0$; $=0$ otherwise.
For a narrow distribution of track angles we can approximate this
with a fixed angle and remove the integration over α_f

$$p(h_p) = \iiint p(\Delta p, R_{max}, V_f)\,\delta[h_p - F(\Delta p, R_{max}, V_{ff}, \bar{\alpha})\,d\Delta p\,dR_{max}\,dV_f$$

We need to examine the characteristics of the multivariate distribution here.



Forward speed of storm appears independent of C



Rmax appears to have a functional dependence o

Given the form of the relationship, it is advisable to use a conditional probability relationship for R_{max} to capture its dependence on Dp, i.e.

$$p(h_p) = \int\int p(R_{\max} \mid \Delta p, V_f)\, d[h_p - F(\Delta p, R_{\max}, V_{ff}, \bar{a})]\, d\Delta p\, dR_{\max}\, dV_f$$

Now we need to relate the surges at a fixed point to the distribution of maximum surges along a line.

The relationship between the local distribution of surges at a specific location, $p(h)$
and the joint probability of peak surges from an event and the alongshore distribution of the surges, $p(h_p, x)$
is given by

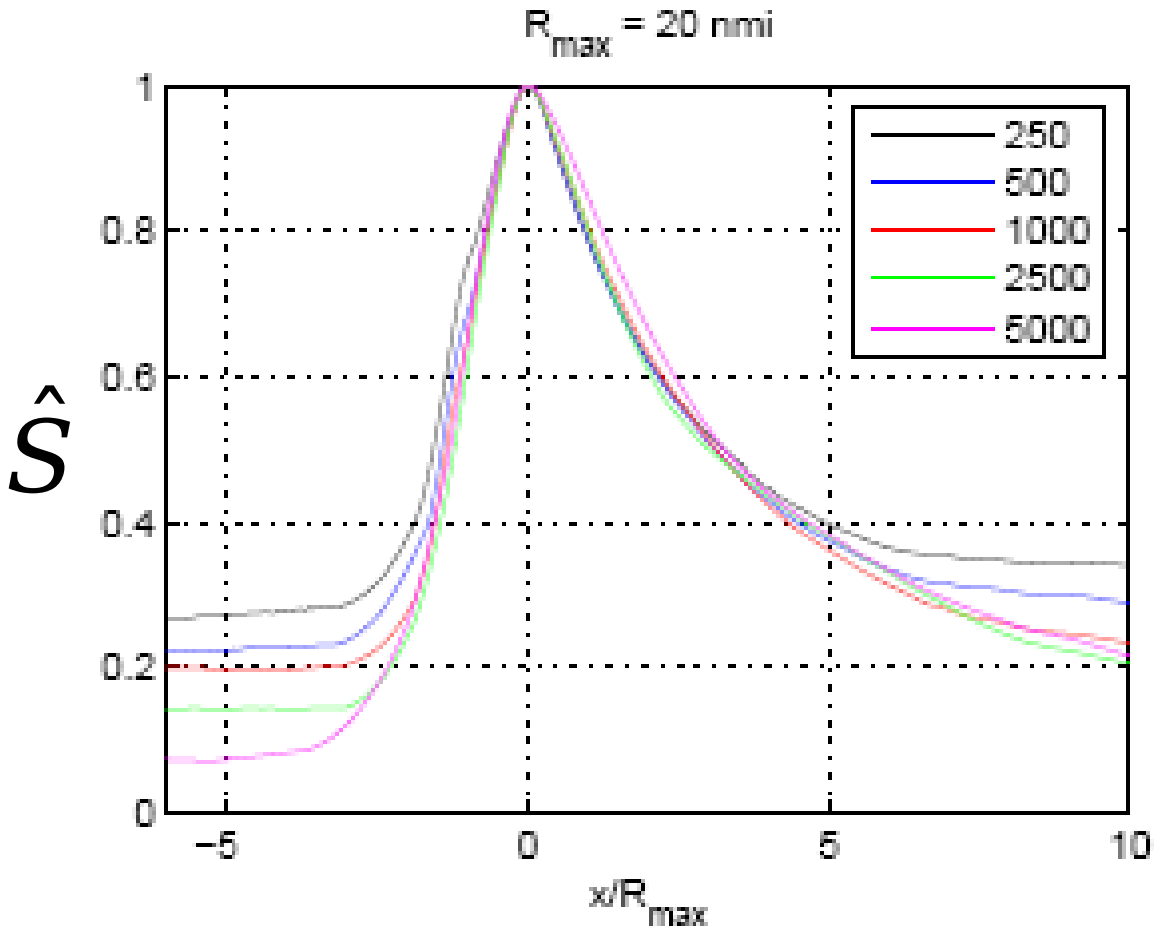
$$p(h) = \int\int p(h_p, x)\, d[h - y(h_p, x)]\, dx\, dh_p$$

Where $y(h_p, x)$ is a spatial operator that relates the distribution of surge heights along the coast to th
surge heights at a given location, x.

$d(z)$ is the Dirac delta function, in which z is just an arbitrary real argument, = 0 for z≠0; and =
This function is related to the Heaviside function via the relationship

$$H(z) = \int_0^z d(z)\, dx$$

is the Dirac delta function, in which z is just an arbitrary real argument,
which is related to the Heaviside function via the relationship, H(z) = 0 for z<0; = 1 for z>0.



The nondimensional surge has an even more consistent shape as a func
of nondimensional distance from the location of peak surge x/R_{max} for m
storm sizes.

The definition of an equivalent time for an event of size η to occur at a specific site versus the same an event anywhere in the domain is given by the relationship

$$I_e = \frac{T_R(h)}{T_R(h_p)}$$

For a Gumbel Distribution we have the classic double exponential form governed by

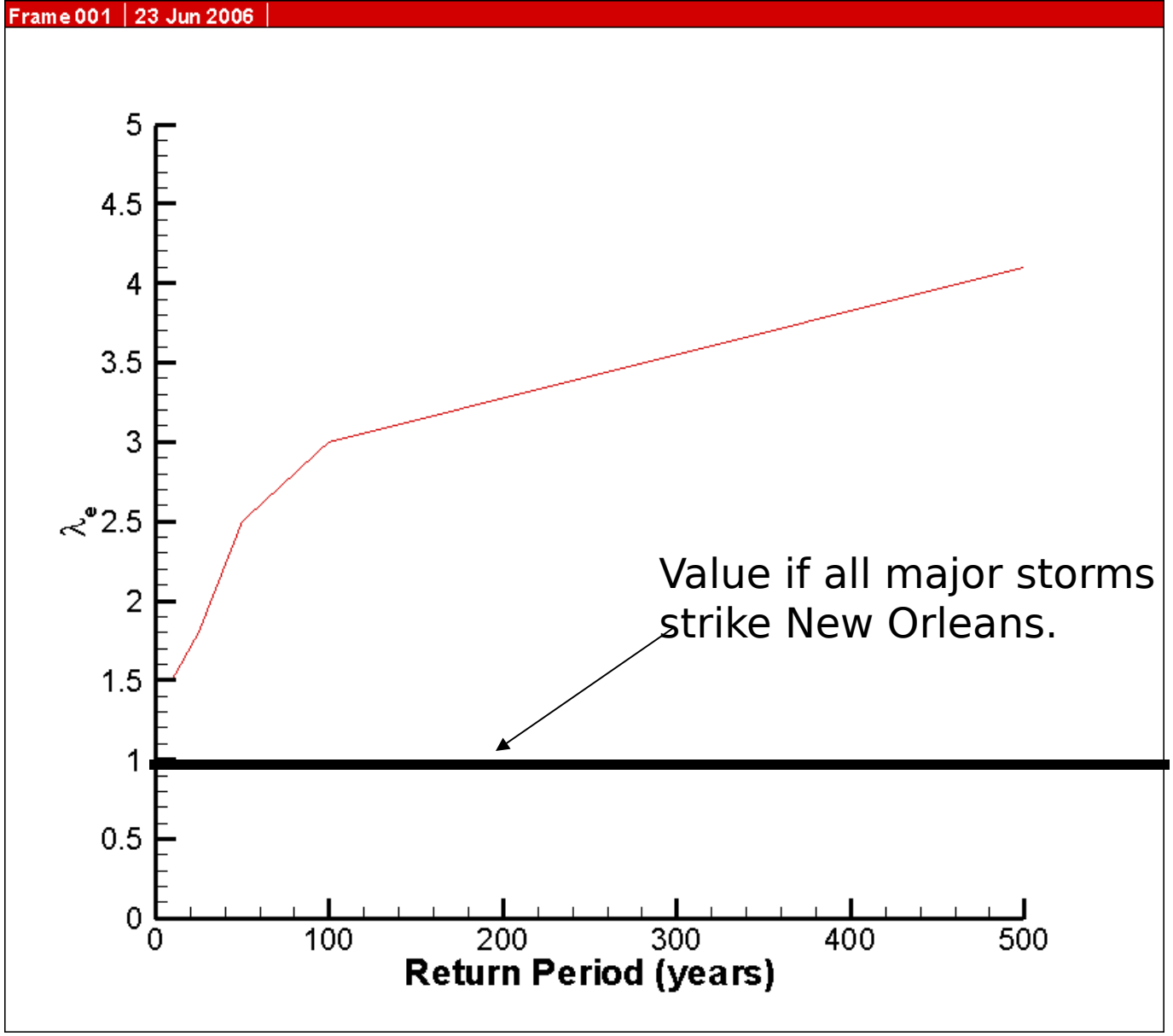
$$F(\hat{h}) = e^{-e^{-\hat{h}}} \quad ; \quad p(\hat{h}) = \frac{\partial F(\hat{h})}{\partial \hat{h}}$$

where

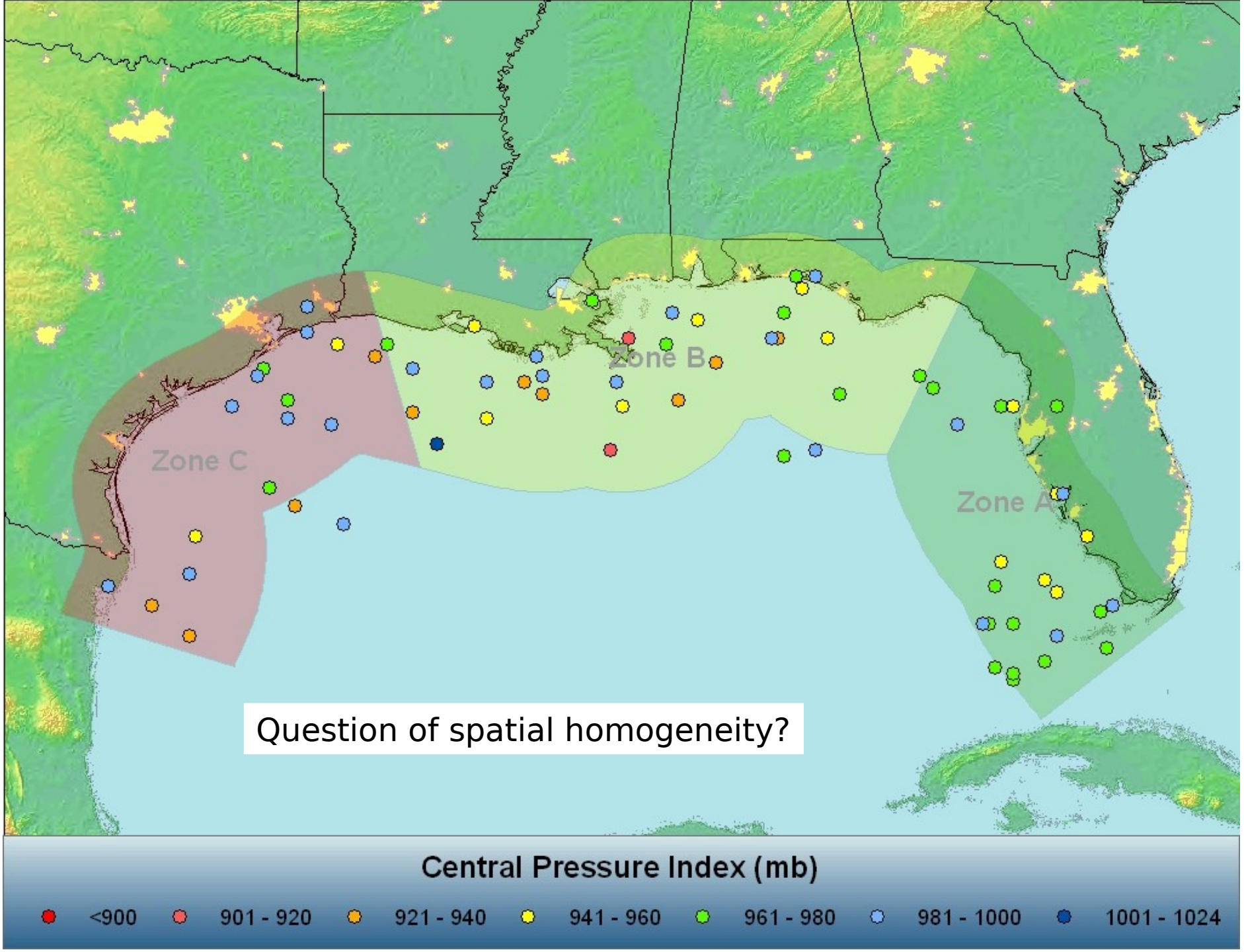
$$\hat{h} = \left(\frac{h - a_0}{a_1} \right)$$

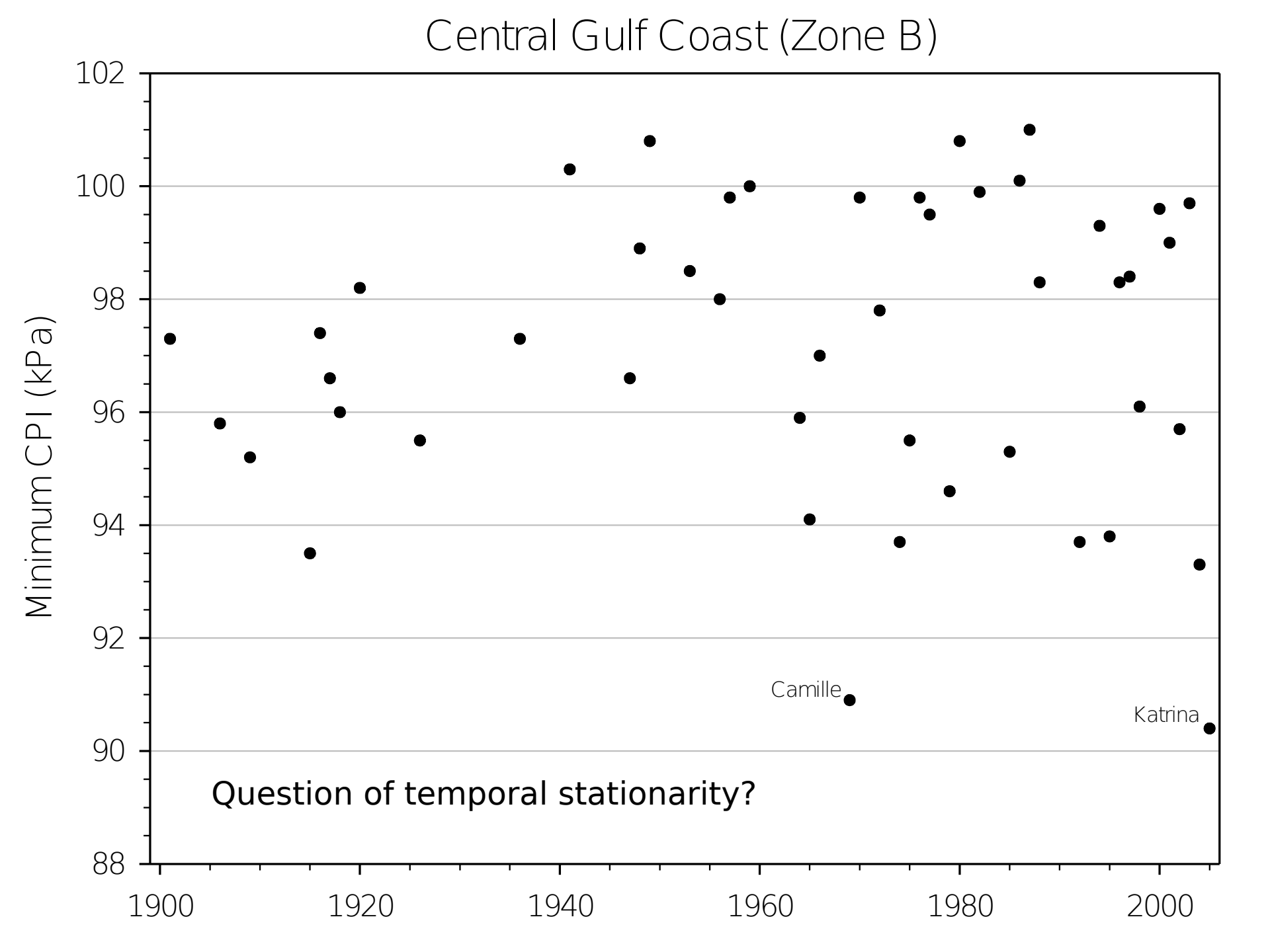
The 3-parameter distribution can be estimated via the generalized transform

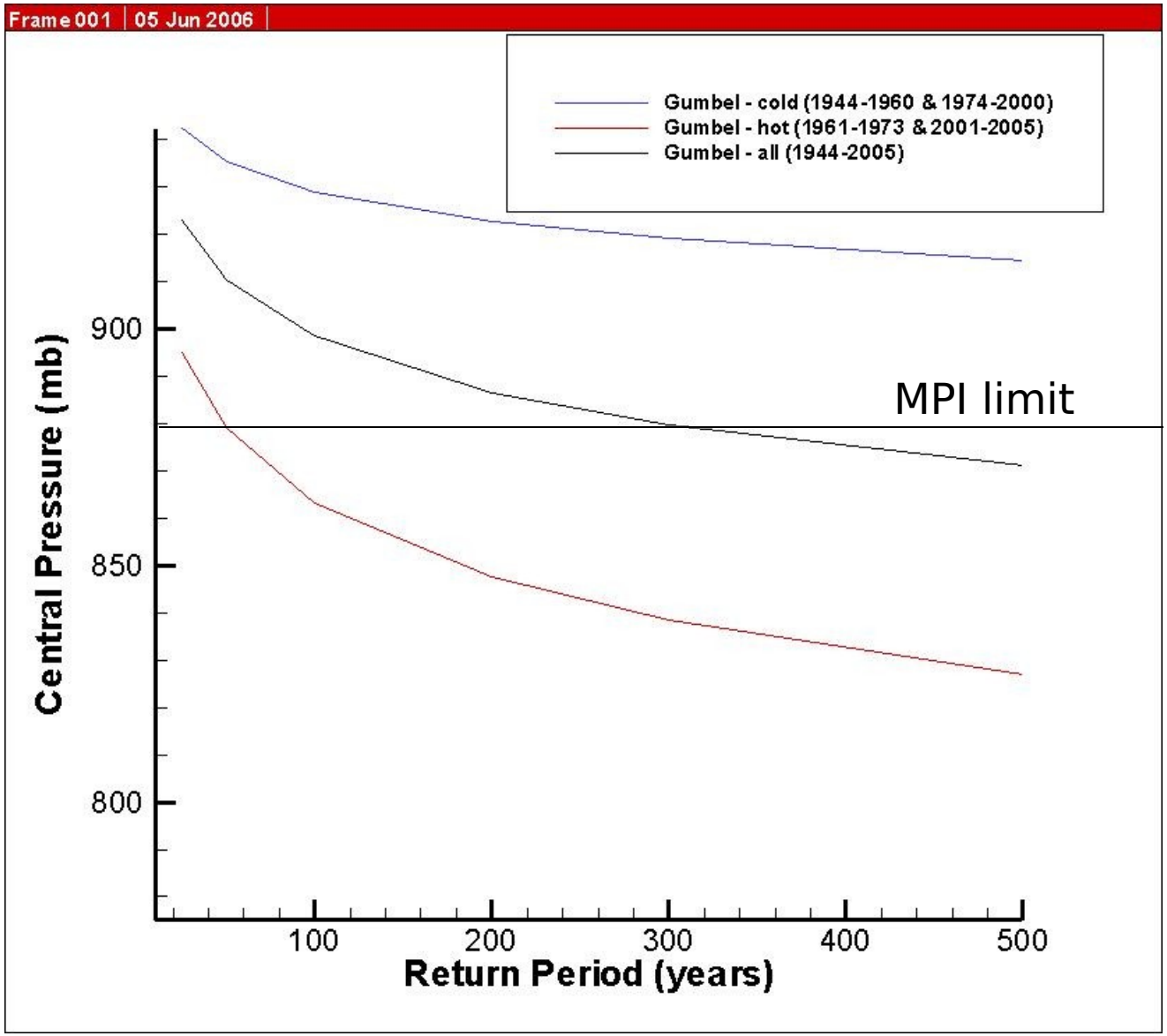
$$\hat{h} = b_0 + b_1 \left(\frac{1 - e^{-b_2 h}}{b_2} \right)$$



Interpretation: The largest 100-year surge within the entire 600 nm length o
Included in this analysis would represent a 300-year surge at a fixed location
area is considered homogeneous.


Zone C
Zone B
Zone A
Question of spatial homogeneity?
Central Pressure Index (mb)
<900
901 - 920
921 - 940
941 - 960
961 - 980
981 - 1000
1001 - 1024


Central Gulf Coast (Zone B)
Minimum CPI (kPa)
102
100
98
96
94
92
90
88
1900
1920
1940
1960
1980
2000
Camille
Katrina
Question of temporal stationarity?



Subdividing time indicates that both frequency and intensity of storms inc
During favorable years versus unfavorable years.

Some preliminary findings:

Angle range is probably much smaller than assumed in JP

Forward velocity of around 11 knots should suffice to represent storm surge for most of this area

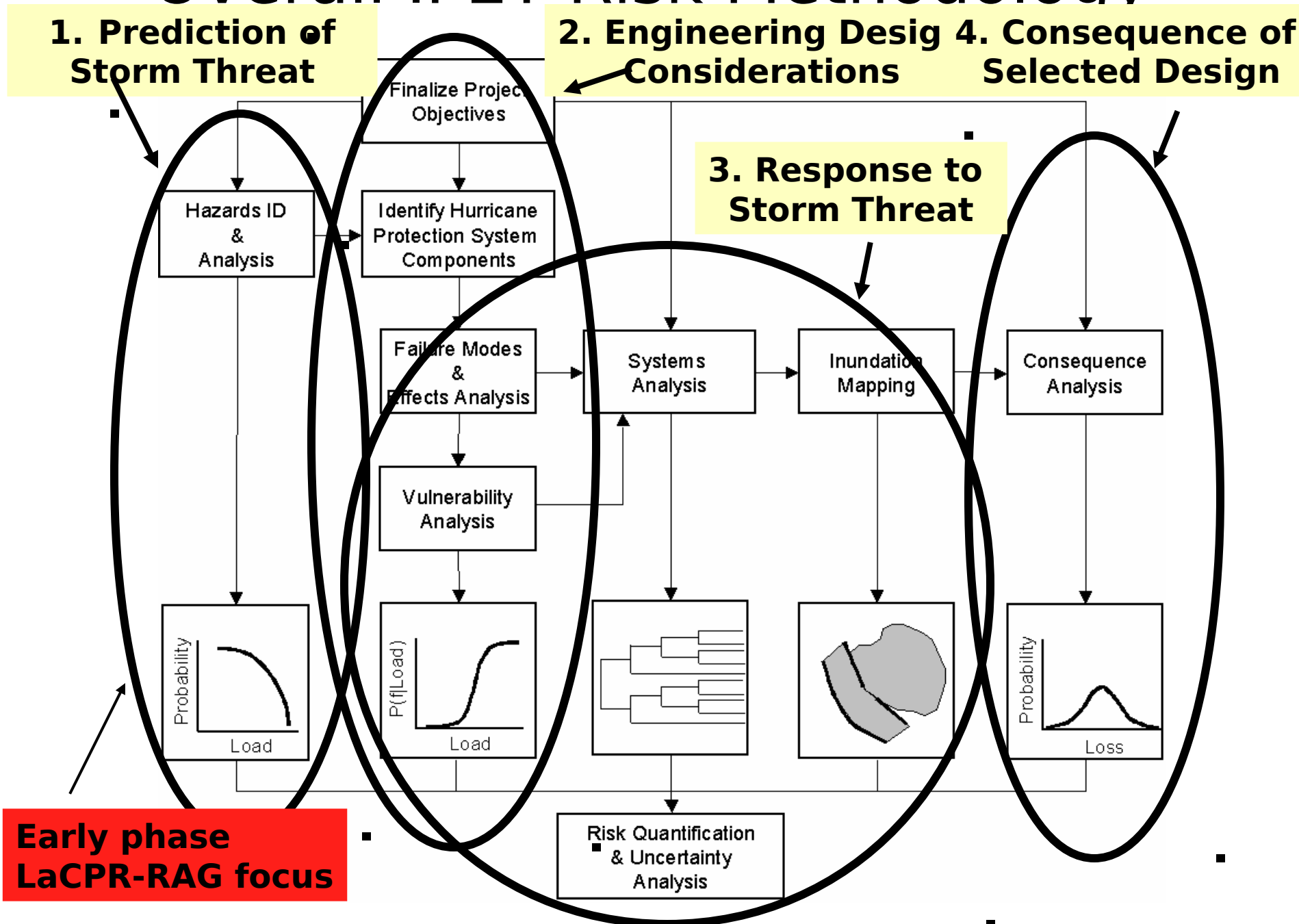
Curvature is fairly small for large storms

This leaves only Rmax and Cp as the primary variables – along with decay during approach to coast and proper specification of wind field and waves

Rmax and Cp cannot be treated as independent

For a specified risk level, selection of appropriate Rmax-Cp combinations may yield a sensible screening storm set

Overall IPET Risk Methodology



RISK ASSESSMENT FINDINGS:

Accuracy of estimates depends on getting the “details” ri

Storm decay during approach to coast is significant

Large storms cannot be predicted via carte blanch analysi
all storms

Set of “screening” storms has been delivered for initial an
of design alternatives

FUTURE DIRECTIONS

Complete careful analysis of surge probabilities for presen
system – compare to FEMA results

Complete careful analysis of surge probabilities for select
hurricane protection systems

QUESTIONS??